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NEW AMERICA

MICHAEL A. CALABRESE

SPECTRUM SILOS TO GIGABIT WI-FI

SHARING THE 5.9 GHZ 'CAR BAND'

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About the Author

Michael A. Calabrese directs the Wireless Future Project at New America, a non-profit think tank based in Washington, D.C. As part of the New America's Open Technology Institute, he develops and advocates policies to promote ubiquitous, fast and affordable wireless broadband connectivity, including the reallocation of more prime spectrum for shared and unlicensed access.

Calabrese has served as an appointed Member of the U.S. Department of Commerce Spectrum Management Advisory Committee (CSMAC) since 2009. He also served as an Invited Expert on the President's Council of Advisors on Science and Technology (PCAST) spectrum reform working group during 2011-2012.

Calabrese previously served as Vice President of New America (2003-2010), as General Counsel of the Congressional Joint Economic Committee, as director of domestic policy at the Center for National Policy, as a counsel at the national AFL-CIO, and as a clerk to California Supreme Court Justice Allen E. Broussard.

Calabrese is a graduate of Stanford Law and Business, where he earned a JD/MBA degree; and a graduate of Harvard College, where he earned a B.A. in Economics and Government.

About New America

New America is dedicated to the renewal of American politics, prosperity, and purpose in the Digital Age. We carry out our mission as a nonprofit civic enterprise: an intellectual venture capital fund, think tank, technology laboratory, public forum, and media platform. Our hallmarks are big ideas, impartial analysis, pragmatic policy solutions, technological innovation, next generation politics, and creative engagement with broad audiences.

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About the Wireless Future Project

New America's Wireless Future Project (WiFu) develops and advocates policies to promote ubiquitous, fast and affordable wireless broadband connectivity, mobile broadband competition, and more efficient spectrum use, including the reallocation of more prime spectrum for shared and unlicensed access. WiFu operates as part of New America's Open Technology Institute.

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EXECUTIVE SUMMARY

The enormous and increasing economic value of unlicensed spectrum for both personal and business productivity is well-documented. In addition to generating more than $200 billion in value for the U.S. economy each year, unlicensed spectrum serves as an incubator of wireless innovation, including as the connective tissue of the emerging Internet of Things. A single application – Wi-Fi – already carries between 60 and 80 percent of all mobile device data traffic, making wireless Internet access far more available, fast and affordable for consumers.

Unfortunately, there are obstacles to extending and expanding the public interest benefits of Wi-Fi. One challenge is that the unlicensed bands themselves are becoming congested, particularly in cities and other densely populated areas where many users are sharing spectrum in order to operate increasingly high-bandwidth applications like video chat and streaming video. Although unlicensed bands are used very efficiently – due to sharing and small-area re-use of spectrum – the FCC has not increased access to unlicensed spectrum at the same pace as it has for licensed services.

A second related challenge to the nation's broadband goals is throughput capacity. With more and more users demanding increasingly high-bandwidth and real-time applications, such as high-definition video calling and streaming, the 20 megahertz wide channels that characterize today's Wi-Fi do not offer enough capacity to accommodate the projected increases in demand for mobile data. Wider channels will be critical to fuel very high-bandwidth apps and pervasive connectivity. This is particularly true in the enterprise environment and in user-dense venues such as schools, hotels, retail malls and sporting events.

As Wi-Fi transports an increasing majority of the nation's mushrooming mobile data traffic, Americans will need both more unlicensed spectrum and the wider channels necessary to handle higher-bandwidth applications and higher-density demand. Opening large contiguous tracts of spectrum in the 5 GHz band for unlicensed sharing is key to creating the "wider pipe" required for gigabit Wi-Fi networks.

Wi-Fi using the IEEE's 802.11ac standard is designed specifically to operate on the wider, contiguous channels available only in the 5 GHz band. Using 802.11ac, Wi-Fi routers can support multiple, simultaneous high-bandwidth uses, such as parallel streams of very high-definition video, and with better performance. The benefits of leveraging 80 and 160 megahertz channel sizes in the 5 GHz band include gigabit network capacity, enhanced performance for video, improved hotspot coverage and longer battery use. Realizing this public benefit will depend, to a considerable degree, on unlicensed sharing of at least the lower portion of the 5.9 GHz band.

Currently, the 75 megahertz at the top of the U-NII-4 band (from 5850 to 5925 MHz) is allocated on a primary basis for Intelligent Transportation Systems (ITS), a set of technologies the auto industry is developing for future vehicle-to-vehicle (V2V) and possibly vehicle-to-infrastructure (V2I) wireless signaling systems. The ITS band is channelized for auto industry use of a specialized IEEE 802.11 standard known as Dedicated Short-Range Communications (DSRC). More than 15 years after the FCC allocated the band to the auto industry on a co-primary basis, the band mostly lies fallow – even as wireless technologies have flourished as an industry.

When ITS America initially petitioned the FCC for a dedicated band of spectrum, it emphasized non-safety services such as navigation assistance, in-vehicle signage, driver advisories, toll collections and fleet management for commercial enterprises. Today the focus of DSRC technology, at least for the U.S. Department of Transportation (DOT) and its safety agency, the National Highway Traffic Safety Administration (NHTSA), has shifted to very narrowband vehicle-to-vehicle signaling applications designed to warn drivers of impending vehicular hazards and thereby avoid accidents before they occur. Real-time V2V safety applications require at most three channels (30 megahertz). The auto industry wants to retain near-exclusive use of the full 75 megahertz, without an auction and at no charge, but most of it would be used for commercial applications unrelated to safety. Furthermore, most of these non-safety applications are already being delivered today over general-purpose wireless networks (e.g., cellular and Wi-Fi).

Policymakers grappling with the question of whether DSRC systems can share all or at least part of the 5.9 GHz band with Wi-Fi and/or other low-power unlicensed technologies should consider the broader context in which a V2V mandate would be implemented:

First, there is a critical distinction between DSRC safety-of-life applications and DSRC informational applications. Non-safety DSRC applications are likely to include in-car information that enables services such as turn-by-turn directions, traffic and weather alerts, wireless payments at gas stations or parking garages, and display advertisements from roadside vendors. In making spectrum allocations, it is important to identify and separate out the spectrum requirements for safety-of-life applications specifically. Most of the informational services DSRC technology is touted to deliver are already publicly available via smartphone applications and other mobile edge providers. And as ubiquitous, high-speed cellular and Wi-Fi connectivity increasingly give drivers and their passengers the ability to access any mobile app or service anywhere, the utility, efficiency and equity of an exclusive and free band of spectrum for duplicative and competing auto industry applications is rightly called into question.

Second, there are a growing number of alternative technologies that can also prevent motor vehicle accidents and do so far sooner. DSRC is not the exclusive path to crash avoidance. Increasingly sophisticated crash-avoidance radar, lasers (LIDAR), cameras, automatic braking, ultrasonic sensors, drowsiness detection and other onboard sensors make each individual car immediately more aware and capable of avoiding accidents regardless of how many other vehicles on the road are similarly equipped. These driver-assist safety applications are already available and will soon be standard features in the majority of new model cars. In contrast, even if NHTSA mandates V2V systems in all new model cars beginning in 2020, the agency estimates it could be 20 to 30 years or longer before V2V is fully adopted and effective. Ultimately, the future is likely to be dominated by a mix of semi- and fully-autonomous vehicles that use a combination of driver-assist technologies to automatically sense-and-avoid accidents. Companies including Google have already extensively road-tested fully autonomous vehicles and the new Tesla Model S includes an "autopilot" system integrating cameras, radar, GPS and ultrasonics. None of these driver-assist or autonomous car safety systems use or rely on DSRC.

> **A single application – Wi-Fi – already carries between 60 and 80 percent of all mobile device data traffic, making wireless Internet access far more available, fast and affordable for consumers.**

Even if NHTSA adopts a V2V mandate, most of the ITS band would not be used for real-time crash avoidance or public safety purposes. From the outset, the auto industry has emphasized other potential DSRC applications in addition to real-time V2V safety. Real-time V2V safety-of-life applications are inherently narrowband and designed to require only a fraction of the 75 megahertz of spectrum currently allocated for ITS and DSRC technology. When the FCC adopted the channelization plan for DSRC in 2003, it allocated one 10 MHz channel specifically to V2V basic safety messaging. NHTSA has subsequently taken the position that crash-avoidance signaling must be limited to a single dedicated 10 MHz channel that is not shared with non-safety applications. Two additional channels (a total of 30 MHz) could be used for real-time safety applications.

Global developments reinforce the fact that real-time safety applications using DSRC require at most 30 megahertz of the larger 5.9 GHz band. Both the EU and Japan have allocated considerably less spectrum specifically for safety-related DSRC systems. In Europe, regulators concluded that two DSRC channels (20 megahertz) are sufficient for "time critical road safety applications" – and another 10 megahertz for non-critical but safety-related applications. Japan has taken an entirely different approach, focusing on non-time critical roadside applications (e.g. tolling) and in any case using entirely different bands of spectrum than the U.S. and Europe.

> **Vehicles themselves are also becoming "smart" by integrating cellular and/or Wi-Fi connectivity to cloud-based applications and the wider Internet.**

Non-safety-of-life, informational DSRC services will be required to operate on other DSRC channels and could have much higher bandwidth needs. These services are wider-band, less delay-sensitive and typically premised on connectivity to the Internet or other external data sources. Although the auto industry would gain some competitive and financial advantage from free access to 5.9 GHz spectrum, these non-safety, informational DSRC applications (most of which are already available to consumers through smartphone and tablet apps) would operate on different service channels separate from basic safety applications.

Fifteen years ago it sounded cutting edge to envision DSRC connectivity delivering a host of informational services to drivers that would provide turn-by-turn directions, improve traffic flow, provide in-vehicle displays of signage, send driver notification advisories (e.g., bad weather or construction ahead), and fleet management. Today most cars on the road are already "connected." But that connectivity is provided by general-purpose cellular and/or Wi-Fi networks that power an innovative and constantly evolving variety of competing cloud-based applications to the driver's (or passenger's) smartphone or tablet. Vehicles themselves are also becoming "smart" by integrating cellular and/or Wi-Fi connectivity to cloud-based applications and the wider Internet. DSRC services, if they ever happen, would compete with what the market is already providing over general-purpose wireless networks – and this will only increase as 5G networks are deployed and Wi-Fi becomes more accessible.

Cisco and Qualcomm have developed competing proposals for sharing the 5.9 GHz band between automotive and general unlicensed use. Under Cisco's proposal, if an unlicensed device operating anywhere in the band detects a DSRC transmission (e.g., a passing vehicle or fixed roadside infrastructure), the device would be required to vacate the entire band – as well as 25 MHz of the adjacent U-NII-3 unlicensed band – for at least 10 seconds. The Cisco approach, as currently envisioned, would effectively and needlessly preclude 802.11ac Wi-Fi, or future variations of unlicensed broadband or device-to-device access, in 100 MHz of spectrum. The proposal would, at best, fragment the Wi-Fi band, require a complete retooling of existing 802.11ac devices, and increase device costs – all of which undermine the FCC's goal in proposing the 5.9 GHz band as an extension of the U-NII bands for very wide-channel use by 802.11ac Wi-Fi.

The leading alternative to the Cisco approach, proposed by Qualcomm, would reorganize the 5.9 GHz band to give delay-sensitive V2V and vehicle-to-infrastructure (V2I) safety applications exclusive use of three channels, while sharing the remainder of the band (45 megahertz) between unlicensed and non-safety DSRC applications. Qualcomm's proposal would move safety-of-life DSRC applications to the three 10 MHz channels at the top of the band. Unlike the FCC's proposal, Qualcomm's approach is premised on segmenting the band and giving V2V and V2I safety-of-life applications exclusive use of three channels not shared with Wi-Fi. Other DSRC channels used for non-safety-of-life applications would be 20 MHz wide and shared. Since NHTSA has not yet adopted a mandate for V2V – and has said that the industry will be given a multi-year transition period – an expedited decision on the future of sharing the band will not necessarily cause undue delay even if it involves some additional testing.

Both DSRC safety-of-life applications and expanded broadband capacity for Wi-Fi would deliver important benefits for virtually all Americans. As the FCC tentatively concluded in its 2013 Notice of Proposed Rulemaking, the public interest would best be served if the two services can coexist and share at least a portion of the 5.9 GHz band without causing harmful interference to DSRC operations – particularly V2V crash avoidance. Expanding the 5 GHz unlicensed access into the lower portion of the 5.9 GHz band, while protecting real-time safety applications on three dedicated DSRC channels, is a win-win solution critical to achieving both the FCC's goal of gigabit Wi-Fi connectivity and the Department of Transportation's goal of deploying narrowband vehicle-to-vehicle communication systems to enhance auto safety.

We therefore recommend that the FCC develop and release a Public Notice during the first quarter of 2016 proposing a process and timeline to test both approaches. Assuming that both the Cisco and Qualcomm proposals are technically feasible, it seems likely the FCC will conclude that the Qualcomm approach (or a variation of it) strikes a better balance between DOT's interest in promoting auto safety and the Commission's interest in promoting ubiquitous broadband connectivity and innovation. The critical factor in striking this balance is the distinction between real-time safety and non-safety DSRC applications described above. By dedicating three channels exclusively to DSRC safety the Qualcomm proposal greatly reduces the risk of unlicensed device interference with time-critical safety-of-life applications, while at the same time adhering to the evolving principles of spectrum efficiency and flexibility that the FCC increasingly applies to non-safety wireless services, particularly to those that are similar to and even compete with applications available on general purpose networks.

A decision to maintain an exclusive and underutilized spectrum allocation for non-safety-of-life DSRC applications would contradict the FCC's commitment to more flexible and efficient spectrum management principles. The Commission should continue to move away from silos of special-purpose spectrum bands and toward more intensively-used and flexible general-purpose use of spectrum. As both the FCC's 2002 Spectrum Policy Task Force and the FCC's 2010 National Broadband Plan emphasized, exceptions made for public safety or other public interest allocations should be narrowly defined "and the amount of spectrum . . . limited to that which ensures that those [compelling public interest] objectives are achieved." The effectively exclusive allocation and non-use of most of the 75 megahertz allocated for DSRC contradicts the Obama Administration's historic initiative to open underutilized federal bands for sharing to the greatest extent feasible. As the PCAST recommended and NTIA and the Department of Defense and other federal agencies have increasingly agreed: "The essential element of [the] new Federal spectrum architecture is that the norm for spectrum use should be sharing, not exclusivity."

In sum, the FCC and the Obama Administration should expedite a collaborative testing process aimed at a win-win compromise that permits the two services – DSRC and U-NII devices – to coexist and share at least a portion of the 5.9 GHz band without causing harmful interference to V2V crash avoidance and real-time safety-of-life communications. This can be done without undue delay since there are no commercial deployments of either DSRC for safety or 802.11ac for Wi-Fi anywhere on the 5.9 GHz band and NHTSA is expected to give automakers a multi-year transition period before requiring DSRC in every new car sold.

BACKGROUND: THE OPPORTUNITY FOR GIGABIT WI-FI

A. The Emerging Wi-Fi Economy: Solving the 'Spectrum Crunch'

When the Federal Communications Commission (FCC) released its National Broadband Plan in 2010, then-FCC Chairman Julius Genachowski warned of a "looming spectrum crisis" that could choke off the exploding consumer demand for apps and data on mobile devices.[1] Genachowski's dire forecast never materialized. Rather, six years later, the use of Wi-Fi to offload most mobile device traffic onto fixed, wireline networks has ushered in a revolution in efficient small cell spectrum re-use.[2] Compared to five years ago, when consumers spent less than an hour daily on mobile devices, today American adults spend nearly three hours per day on mobile devices, a majority of their total time consuming digital media.[3] The increasing ability of consumers to connect their smartphones and tablets to high-capacity wireline networks using Wi-Fi and unlicensed spectrum has not only accommodated a nearly 60 percent year-over-year growth rate in mobile data traffic, it has even led to the development of new "Wi-Fi First" business models–such as Republic Wireless, Cablevision's Freewheel and Google's Project Fi–hybrid networks that offer the promise of increasing inter-platform innovation and competition.

Recognizing this trend, FCC Commissioner Jessica Rosenworcel described a few of the enormous consumer and economic benefits of Wi-Fi at SXSW last year, stating: "Wi-Fi is how we get online. ... Wi-Fi is how we foster innovation. ... Wi-Fi is also a boon to the economy. ... $140 billion annually–and it's only going to grow. ... We need to keep it coming. We need to make Wi-Fi a priority in spectrum policy."[4] FCC Chairman Tom Wheeler similarly observed that while access to unlicensed spectrum draws less public attention than multi-billion dollar auctions for licensed spectrum, "as the remarkable success of Wi-Fi demonstrates, [unlicensed spectrum] literally is an indispensable element in the provision of broadband today."[5] Rosenworcel and fellow FCC Commissioner Michael O'Rielly warned in a joint blog post that because "Wi-Fi spectrum bands are wildly popular ... with more and more people and devices taking advantage of this technology, these bands are getting congested."[6]

Today more than 63 percent of U.S. households have one or more Wi-Fi networks, and the adoption rate is expected to rise to 86 percent by 2017.[7] Virtually every licensed device incorporates Wi-Fi and most service providers depend on Wi-Fi to make high data-rate applications like video feasible and affordable to users. However, much of the vast Wi-Fi device ecosystem is not connected to any cellular network. For example, more than 90 percent of iPads and other tablets are used exclusively on wireline connections via Wi-Fi, as are virtually all laptops and netbooks.

Ten years ago most people assumed that the future of mobile Internet access would be licensed cellular networks. But technology has a way of unsettling expectations. Today, unlicensed spectrum carries the majority of all mobile device data traffic, and soon it will carry twice the amount of traffic as licensed spectrum and carrier networks. Cisco's Virtual Networking Index estimates that Wi-Fi carried 57 percent of all U.S. mobile data traffic in 2014, and projects that 66 percent of U.S. mobile data traffic will be transported via Wi-Fi, rather than licensed networks, by 2019.[8] Mobidia, which measures the actual usage of tens of thousands of consumers, reports that Wi-Fi is already carrying an average of 80 percent of total mobile device data traffic.[9] This is the same level of Wi-Fi offloading projected for Western Europe by the end of 2016, according to a European Commission study.[10]

> **Ten years ago most people assumed that the future of mobile Internet access would be licensed cellular networks. But technology has a way of unsettling expectations.**

This trend toward small cell re-use of unlicensed spectrum will only increase. Americans spend a growing share of their time online using a mobile device–and increasingly they use high-bandwidth applications (video chat, music and video streaming, social media) indoors and in other stationary locations where connecting over a faster and less expensive fixed LAN via Wi-Fi is most popular.[11] The application driving data demand – video – is the most nomadic, and is expected to surge to 75 percent of total U.S. mobile data traffic by 2019 and 80 percent globally.[12] Surveys of user behavior show that nearly 85 percent of video on mobile devices is watched at home (50 percent), at work (15 percent), or in other indoor locations. Only 15 percent is watched outdoors or "in transit" and it's likely that an increasing share of this traffic will be covered by Wi-Fi hotspots in the future.[13]

In addition to providing a tremendous boost to wireless broadband capacity and affordability through spectrum re-use, the unlicensed bands have also proven to be a sandbox for innovation. As former GigaOm analyst Kevin Fitchard noted, "[u]nlike cellular spectrum, which is licensed and tightly controlled by the operators, the openness of the unlicensed bands allows anyone with a new idea to go for broke."[14] One reflection of how open, unlicensed spectrum access lowers the barriers to entry and innovation is the proliferation of new device certifications on these bands. Overall, there are far more unlicensed than licensed devices.[15] More devices have been certified to use the 2.4 GHz unlicensed band (more than 22,000) than in any other band (the FM band was second with 7,275 devices certified as of early 2013). About two billion Wi-Fi capable devices were sold in 2013 alone and the Wi-Fi Alliance projects that sales of devices with Wi-Fi connectivity will exceed 4 billion by 2020 (a six-fold increase from 2010).[16]

Unlicensed Wi-Fi routers, chips and services are a rapidly-growing, multi-billion-dollar industry. But more important for the economy overall is the tremendous multiplier effect that Wi-Fi has on the use and utility of the Internet by making a single wired connection available for shared use on a very low-cost, do-it-yourself basis. This generates enormous consumer welfare. Because Wi-Fi routers are inexpensive and plug-and-play, they enable multiple users to access higher-speed broadband connections in a growing majority of homes and business locations. Although Wi-Fi hotspots deployed by ISPs, such as AT&T and Comcast, have received considerable attention recently, studies that crowdsource actual smartphone usage show that more than 90 percent of Wi-Fi traffic continues to flow over unmanaged connections self-provisioned by individual households and businesses.[17] In fact, Wi-Fi connections in homes, businesses, and in rapidly proliferating public hot spots have proven to be complementary and cost-saving to both commercial wireless carriers (which need fewer base stations and less licensed spectrum) and to wireline ISPs seeking to give their customers the ability to access content away from their home wired connections.[18]

A series of economic studies have documented the steadily increasing economic value of unlicensed spectrum use for both personal and business productivity. A pair of 2014 studies by Columbia University economist Raul Katz estimated that the broader set of applications currently operating in unlicensed spectrum bands in the United States (primarily Wi-Fi and RFID) generated a total economic value of $222 billion in 2013, which he projected to increase to $531 billion by 2017.[19] A second pair of economic studies by the Consumer Technology Association (formerly the Consumer Electronics Association) estimates that unlicensed spectrum generates $62 billion in retail sales value for devices and over $200 billion when combined with "unlicensed spectrum's value in terms of cost savings to individuals and firms."[20]

Unlicensed spectrum as a public resource increasingly serves as an incubator of wireless innovation. Although Wi-Fi is the best known unlicensed standard, the expansion of unlicensed spectrum has also enabled other communications technologies, such as Bluetooth, ZigBee, z-Wave, Near Field Communication (NFC) and wireless HD connections, "technologies [that] have opened new frontiers of communications for consumers."[21] In their valuation study, Stanford economists Paul Milgrom and Jonathan Levin observed that "the primary benefits of unlicensed spectrum may very well come from innovations that cannot yet be foreseen. The reason is … that unlicensed spectrum is an enabling resource. It provides a platform for innovation upon which innovators may face lower barriers to bringing new wireless products to market."[22]

> **Unlicensed spectrum as a public resource increasingly serves as an incubator of wireless innovation.**

The benefits of unlicensed spectrum extend far beyond wireless broadband. Cisco's Visual Networking Index projects a tripling of machine-to-machine connections by 2019, nearly half of which are expected to be in home applications, such as home automation, monitoring, asset tracking, and security and surveillance video.[23] Open wireless strategies (Wi-Fi and other unlicensed technologies) are already dominant in a number of industries that are rapidly incorporating wireless connectivity, making up 70 percent of smart grid communications, 80 percent of wireless healthcare solutions, over 90 percent of wireless tablet connectivity, nearly all RFID inventory and asset tracking, as well as a growing share of the emerging Internet of Things.[24] Using unlicensed spectrum, power companies have been able to deploy advanced smart grid solutions without vying for their own piece of spectrum – an entry cost prohibitive to most innovators. Thanks primarily to the availability of unlicensed spectrum at 900 MHz, in the U.S. only one major provider in the smart grid market uses its own licensed spectrum.[25] In contrast, Europe's lack of access to unlicensed low-band spectrum equivalent to the U.S. 900 MHz band has resulted in only 15 percent wireless deployment (the rest uses wireline) – a situation that has stagnated the deployment of smart grid technology in European markets.[26]

Unlicensed spectrum is becoming the connective tissue of the Internet of Things. Energy monitoring, environmental monitoring and controls, mobile healthcare monitoring, industrial automation, intelligent transportation networks, control systems (for agricultural machinery, toll booths, traffic lights) are seeing rapid growth with declining costs to consumers.[27] As the as the President's Council of Advisors on Science and Technology (PCAST) observed in their 2012 report and recommendations, by 2020 "the connected device market is expected to be dominated not by mobile phones, as it is today, but by machine to machine (M2M) devices – as many as 50 billion of them by some estimates.[28]

> **The overall impact of high-capacity, ubiquitous and affordable wireless connectivity for the nation's economy is enormous.**

The overall impact of high-capacity, ubiquitous and affordable wireless connectivity for the nation's economy is enormous. A May 2013 study by the McKinsey Global Institute examined 100 disruptive technologies and ranked the mobile Internet first, with an estimated global economic impact of $3.7 to $10.8 trillion by 2025 (nearly double the impact of the second most valuable technology, the automation of knowledge work).[29] The impact of wireless connectivity on the U.S. economy is amplified because it is what Jason Furman, chairman of the president's Council of Economic Advisors, called "a General Purpose or 'platform' technology, meaning that improvements in communication technologies stimulate innovation across a wide variety of other sectors."[30] The implications for innovation and economic competitiveness led the FCC's National Broadband Plan to recommend the reallocation of an additional 500 MHz of licensed and unlicensed spectrum by 2020 in the prime frequencies below 3.7 GHz. However, even if this goal is met, since few substantial new allocations of exclusively-licensed spectrum are identified beyond the 2016 TV band incentive auction, expanded use of unlicensed spectrum for Wi-Fi traffic will be necessary to absorb projected demand, to ensure consumers higher-speed connections, and to promote innovation in M2M connectivity more broadly.

Two Obstacles to America's Surging Unlicensed Economy

Unfortunately, despite the proven importance of unlicensed spectrum access for consumers and the overall economy, two obstacles to extending its provisioning and use are widely recognized. One challenge is that the unlicensed bands themselves are becoming congested, particularly in cities and other densely populated areas where many users are sharing spectrum in order to operate increasingly high-bandwidth applications like video chat and streaming video. Although unlicensed bands are used very efficiently -- due to sharing and small-area re-use of spectrum -- the FCC has not increased access to unlicensed spectrum at the same pace as it has for licensed services. As a result, the primary Wi-Fi bands are often saturated during peak demand periods in heavily-trafficked areas like shopping and office districts, apartment buildings, sporting events, and other public venues. A 2013 study by CableLabs found that assuming current growth rates in usage, Wi-Fi spectrum in the 2.4 GHz band "is likely to be exhausted in the near-term, and that this will negatively impact Wi-Fi performance for consumers . . . and hinder the nation's broadband goals."[31]

One advantage of Wi-Fi is that many users can simultaneously share the same channel. However, a greater number of users slows throughput, which can in turn disrupt high-bandwidth and latency-sensitive applications like video calls. As Google and Microsoft observed in their joint comments in the 5 GHz proceeding, "[t]his congestion imposes a large cost on consumers because Wi-Fi is the most heavily used method of wireless broadband connectivity and the 2.4 GHz band is the core Wi-Fi band today."[32]

A second related challenge to the nation's broadband goals is throughput capacity. Surveys show that smartphone users generally find Wi-Fi connections, where available, to be considerably faster than commercial 3G and 4G cellular networks.[33] However, with more and more users demanding increasingly high-bandwidth and real-time applications, such as interactive high-definition video calling and streaming, the 20 megahertz wide channels that characterize today's Wi-Fi do not offer enough capacity to accommodate the projected increases in demand, including the demand for interactive, real-time applications such as video calling. Wider channels will be critical to fuel very high-bandwidth apps and pervasive connectivity. This is particularly true in the enterprise environment, and in user-dense venues such as schools, hotels, retail malls and sporting events where the aggregate demand for bandwidth and low-latency will outstrip current Wi-Fi capabilities.

Among the untapped resources that could alleviate "the Wi-Fi crunch," the 5.9 GHz band is among the most promising. The subsequent sections of this paper will demonstrate why expanding 5 GHz unlicensed access into at least the lower portion of the 5.9 GHz ITS band is a win-win solution critical to achieving both the FCC's goal of gigabit Wi-Fi connectivity and the Department of Transportation's goal of deploying narrowband vehicle-to-vehicle communication systems to enhance auto safety.

B. 5 GHz Band: A Unique Opportunity for Gigabit Wi-Fi

As Wi-Fi transports an increasing majority of the nation's mushrooming mobile data traffic, Americans will need both more unlicensed spectrum and the wider channels necessary to handle higher-bandwidth applications and higher-density demand. The FCC recognized this in its 5 GHz NPRM, stating that "[t]he deployment of wide channel bandwidths with higher data rates in the 5 GHz band can help meet the challenge that rapid growth in demand has posed for the wireless industry . . .."[34] In short, opening large contiguous tracts of spectrum in the 5 GHz band for unlicensed sharing is key to creating the "wider pipe" required for gigabit Wi-Fi networks.

Today's principal Wi-Fi band, at 2.4 GHz, provides only three non-overlapping 20 megahertz channels and a maximum data rate of 130-150 Mbps. Three different Wi-Fi standards operate on the 5 GHz unlicensed band: 802.11a, 802.11n and 802.11ac. Only the new 802.11ac standard allows for wireless broadband throughput in excess of 1 gigabit per second, dramatically exceeding the capacity and speed of current Wi-Fi connections.[35] Wi-Fi using 802.11ac is designed specifically to operate on the wider, contiguous channels available only in the 5 GHz band. The IEEE's 802.11ac standard can support multiple, simultaneous high-bandwidth uses, such as multiple parallel streams of very high-definition video, with better performance.

The 802.11ac technology achieves this huge boost in speed and capacity by combining several improvements: wideband channels of 40, 80 and even 160 megahertz (far wider than the three non-overlapping 20-megahertz channels available at 2.4 GHz); extended multiple input, multiple output (MIMO) that enables eight spatial streams (twice as many as 802.11n); denser modulation, using 256 QAM (quadrature amplitude modulation), compared to 64 QAM in 802.11n; and enhanced channel bonding techniques.[36] The benefits of leveraging 80 and 160 megahertz channel sizes in the 5 GHz band include:

Gigabit Network Capacity: Wideband channels will initially more than triple Wi-Fi throughput rates, boosting the quality of experience for both home and enterprise users, including virtually instantaneous downloads and support for many parallel streams of high-definition video with improved spectrum efficiency and reliability.[37]

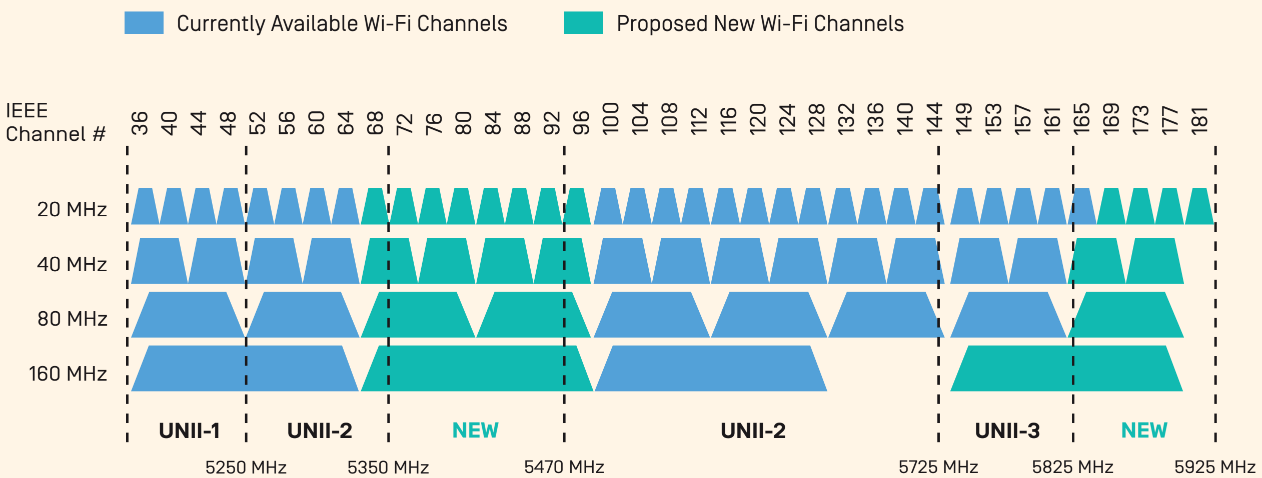
Enhanced Performance for Video: In user-dense environments 802.11ac can deliver many parallel streams of streaming video because MIMO and enhanced channel aggregation route traffic over multiple spatial streams.[38]

Longer Battery Use: With higher data rates, devices consume less battery power since transmission times are far shorter and more efficient.

Improved Hotspot Coverage: The higher capacity of each access point enables relatively high data rates over larger coverage areas, reducing the cost and improving the utility of both indoor networks and shared, public Wi-Fi networks.[39]

Figure 1

Current and potential U-NII (unlicensed) channels subject to the FCC's 5 GHz proposed rulemaking



Source: U.S. Department of Commerce, NTIA, ***Evaluation of the 5350-5470 and 5850-5925 Bands Pursuant to Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012*** (Jan. 2013), p. 3-3, available at https://www.ntia.doc.gov/files/ntia/publications/ntia_5_ghz_report_01-25-2013.pdf.

Contiguous channels of 160 megahertz are needed to realize the full potential of equipment employing the Wi-Fi 802.11ac standard. The FCC's proposal to extend unlicensed access above 5850 MHz and into at least the lower portion of the 5.9 GHz band is one of the few ways to achieve an additional and fully functional 160 megahertz Wi-Fi channel – and gigabit capacity Wi-Fi – for years to come. As the right side of the graphic above shows, extending unlicensed use of the U-NII-4 band up to 5895 MHz would add two 40 megahertz channels, one 80 megahertz channel, and create a contiguous 160 megahertz channel in combination with adjacent U-NII-3 unlicensed spectrum. If the FCC adopts its proposal to harmonize the rules for unlicensed use across the U-NII-3 and new U-NII-4 spectrum (5.725-5.925 GHz), this would allow devices to access 200 megahertz of contiguous spectrum that is fully useful for commercial indoor and outdoor gigabit Wi-Fi.[40] It would also provide a currently missing piece of the FCC's 2013 proposal to expand the availability of unlicensed spectrum for low-power unlicensed use in the 5 GHz band to a total 750 megahertz.[41]

Currently, the 75 MHz at the top of the U-NII-4 band (from 5850 to 5925 MHz) is allocated on a primary basis for Intelligent Transportation Systems (ITS), a set of technologies that the auto industry is developing for future vehicle-to-vehicle and possibly vehicle-to-infrastructure wireless signaling systems. As described further below, the ITS band is channelized for auto industry use of a specialized IEEE 802.11 standard known as Dedicated Short-Range Communications (DSRC). It is evident that because the entire 75 MHz ITS band will not be needed or used for real-time safety applications (discussed in the next section), there is considerable support for the idea that an FCC decision to permit unlicensed devices to share at least the lower portion of the 5.9 GHz band would advance consumer welfare without undermining auto safety applications. As Senate Commerce Committee Chairman John Thune said in support of the Commission's proposal:

> Connected vehicle technology and increased Wi-Fi bandwidth will each have significant benefits for the public. Obviously, the best possible public policy outcome is if the engineers can find a way for both technologies to co-exist in the 5.9 gigahertz band.[42]

While an inter-industry consensus on sharing the band has not yet emerged, there are both technical and economic reasons for optimism. For example, even the Intelligent Transportation Society of America, in its initial comments responding to the FCC's proposal, acknowledged "the expectation that similarities in the technical requirements for DSRC and U-NII devices could facilitate band sharing."[43] Both are based on the IEEE 802.11 standard. The IEEE 802 group explained in its comments supporting shared use of the band that because both the 802.11ac and 802.11p standard used for DSRC are IEEE 802.11 based technologies, "we believe that there is a way forward to address the concerns of the ITS community about potential interference to their system from commercial 802.11 devices."[44]

Since neither DSRC nor 802.11ac Wi-Fi are commercially deployed in the band anywhere in the country, it is imperative that the FCC collaborate with the Administration on the best approach to sharing the band. For example, if collaborative testing shows that unlicensed devices are incompatible with safety-of-life applications using DSRC, such as the narrowband vehicle-to-vehicle (V2V) signaling that NHTSA is on a path to mandating, a decision must be made as soon as possible about whether to move the DSRC safety channels to the top of the band – most likely 5895 to 5925 MHz – furthest away from Wi-Fi operations. This can be done without undue delay since there are no commercial deployments of either DSRC or 802.11ac anywhere in the band across the U.S. and NHTSA is expected to give automakers a multi-year transition period before requiring DSRC in every new car sold. Qualcomm, which makes chips based on both the 802.11p and 802.11ac standards, has emphasized that because the physical characteristics and channelization of the upper portion of the band are the same as the safety channel that DSRC vehicle-to-vehicle prototypes currently use, there would be a minimal need for additional propagation or safety testing.[45] The Qualcomm proposal to reorganize the band and ensure protection of V2V safety-of-life operations is discussed further in Section 5.

AUTO SAFETY, DSRC, AND THE INTELLIGENT TRANSPORTATION SERVICE BAND

A. A Brief History

When Congress passed the Intermodal Surface Transportation Safety Act in 1991, it directed the Department of Transportation (DOT) to begin researching and testing "intelligent vehicle-highway systems" that could improve auto safety.[46] These new technologies would come to include Dedicated Short-Range Communications technology. DSRC is intended to enable real-time wireless communication on both a vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) basis. DSRC, along with automated driver-assist technologies and the development of fully autonomous vehicles, mark an important turning point in automotive safety. In the half century after Ralph Nader's exposé *Unsafe at Any Speed* sparked reforms requiring seat belts, air bags and other passenger protection technologies, the policy approach has been to mitigate the damage from collisions. Now technology is enabling a shift in policy purpose toward avoiding a large share of collisions before they occur.

"We are entering a new era of vehicle safety, focusing on preventing crashes from ever occurring, rather than just protecting occupants when crashes happen," Secretary of Transportation Anthony Fox recently stated.[47] Fox made the statement at an event announcing that ten automakers have agreed to install a core "driver assist" technology – automatic emergency braking systems – as standard equipment in new vehicles. The emergency braking systems "use on-vehicle sensors such as radar, cameras or lasers to detect an imminent collision."[48] Since most crashes are caused by driver inattention or error, research and early deployments in luxury cars show these driver-assist sensing technologies can avoid or at

> **DSRC, along with automated driver-assist technologies and the development of fully autonomous vehicles, mark an important turning point in automotive safety.**

least mitigate rear-end collisions, which are the most common and costly accident type, representing nearly one-third of all collisions and resulting injuries and property damage.[49]

Initially, DOT's early ITS research focused on avoiding accidents with fully automated systems for vehicle control. This was ultimately a premature anticipation of the autonomous car technologies being developed and tested today by Google, Tesla, Mercedes, Volkswagen, Nissan and other leading automakers. DOT's initial work culminated in 1997 with an automated driving demonstration in San Diego.[50] Unlike today's driver assist and autonomous car technologies, which rely on car-based sensing systems, that first generation of automated vehicle development anticipated reliance on roadside systems, including dedicated lanes and costly infrastructure

> **Recognizing the obstacles to scaling this infrastructure across thousands of state, county and local jurisdictions, future development focused on other priorities, especially vehicle-to-vehicle signaling (V2V) using a new radio technology known as Dedicated Short-Range Communications (DSRC).**

installed along every major roadway. Recognizing the obstacles to scaling this infrastructure across thousands of state, county and local jurisdictions, future development focused on other priorities, especially vehicle-to-vehicle signaling (V2V) using a new radio technology known as Dedicated Short-Range Communications (DSRC).

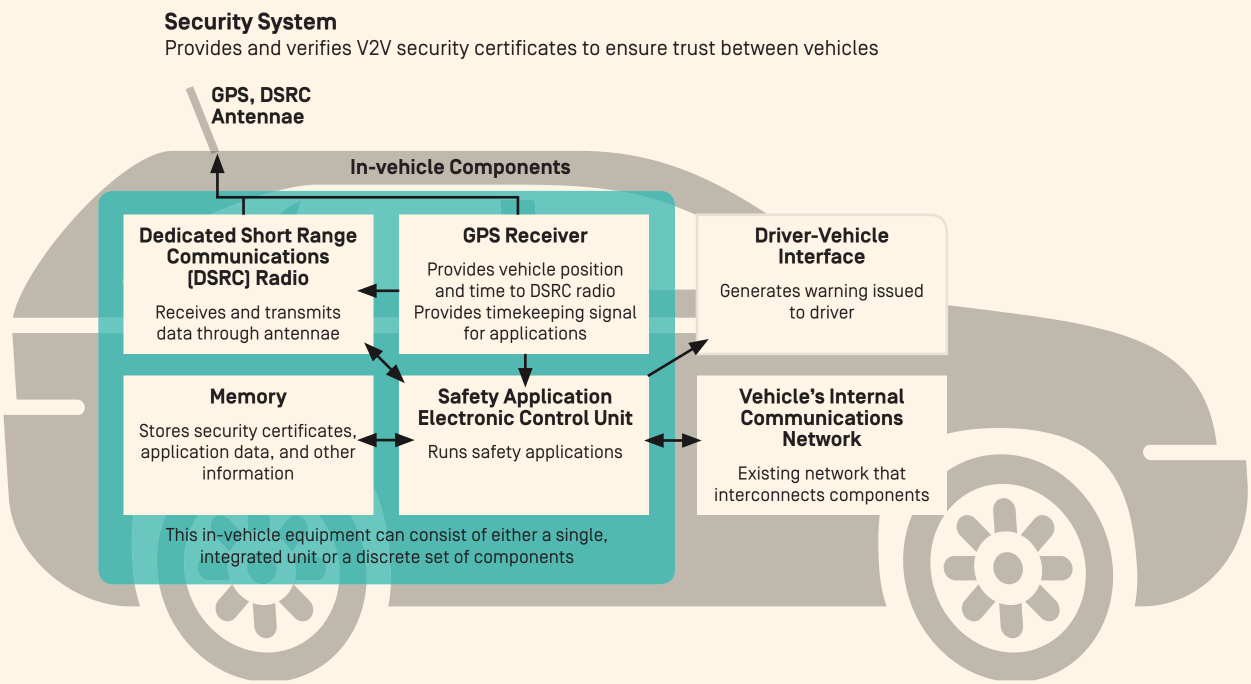
In 1997 ITS America, a trade association focused on the future of auto safety technology, filed a petition asking the FCC to allocate 75 megahertz of spectrum dedicated to ITS and future DSRC deployments. Soon after Congress passed the Transportation Equity Act for the 21st Century of 1998 (TEA-21), which declared that crash avoidance should be a national priority.[51] TEA-21 directed the FCC to consider the spectrum needs associated with "intelligent transportation systems, including spectrum for the dedicated short-range vehicle-to-wayside wireless standard."[52]

In 1999, in response to the petition and TEA-21, the FCC allocated the requested 75 megahertz (5850 to 5925 MHz) for shared use by DSRC technology on a licensed basis. [53] At that time, prior to the emergence of Wi-Fi and cellular broadband data services, there was little if any demand for such high-frequency spectrum for mobile communication. Nor was there any concerted effort by the auto industry during the subsequent decade to develop and deploy the band. The first large-scale test of V2V safety applications in real-world driving scenarios, co-sponsored by DOT and the University of Michigan in Ann Arbor, began in late 2012 and extended into 2014. The Safety Pilot Model Deployment equipped 2,800 vehicles and 27 roadside units. In its 2014 V2V Readiness Report, released in tandem with the agency's pending proposal to mandate V2V in passenger cars and light trucks, DOT's National Highway Transportation Safety Administration (NHTSA) observed that the pilot deployment in Ann Arbor showed that the V2V prototype devices and system worked ("functional feasibility"), "but not necessarily how well they worked," which would require an evaluation of a ubiquitous deployment.[54]

Today, after more than 15 years and hundreds of millions of dollars in DOT subsidies for research and testing, DSRC technology is still neither deployed nor publicly available. NHTSA has a rulemaking underway that proposes to mandate DSRC for vehicle-to-vehicle safety systems in new cars and light trucks within a few years.[55] The rulemaking states that "[i]t is NHTSA's view that, if V2V were not mandated by the government, it would fail to develop or would develop slowly."[56]

Figure 2

In-Vehicle Components of a V2V Safety System[57]



Source: Adapted from Crash Avoidance Metrics Partnership and GAO.

However, even with a mandate, V2V safety systems will not be effective or reliable until there is ubiquitous adoption by most of the U.S. car and truck fleet – a total of more than 270 million motor vehicles that turns over every 14 years on average. A critical mass of DSRC-equipped vehicles is not expected for at least that many years and possibly as long as 37 years, according to NHTSA's 2014 V2V Readiness Report.[58]

In early 2013 the FCC adopted a Notice of Proposed Rulemaking (NPRM) that proposes to permit Wi-Fi and other low-power U-NII (unlicensed) devices to operate across the entire 5.9 GHz band on a secondary and shared basis so as to "increase wireless broadband access and investment."[59] Later that year, in response to the Commission's proposal, the IEEE formed a committee, nicknamed "Tiger Team," to study the feasibility of allowing shared access of the 5850-5925 MHz band between DSRC technology and unlicensed devices. Tiger Team deliberations focused on evaluating two spectrum-sharing proposals, one from Cisco and the other from Qualcomm (these are discussed in Section 5 below). Auto industry representatives did not propose a sharing approach or share data on any of their testing, despite requests from Wi-Fi interests. After 18 months of presentations and debate, the IEEE "Tiger Team" could not come close to consensus and released a report that does not endorse one approach over another.[60] It states that "more work needs to be done beyond the time frame of this tiger team before any definitive technical recommendations could be made."[61]

Recently Cisco, in coordination with the auto industry, announced that it would begin both laboratory and field testing of its proposed approach to sharing the

5.9 GHz band.[62] In August the DOT released a DSRC-Unlicensed Device Test Plan for the stated purpose of better "understand[ing] the impacts of unlicensed devices operating in the DSRC band in order to provide recommendations through NTIA to the FCC."[63] DOT's plan includes, in phases: lab testing, field testing, simulations and analysis.

Congress has also gotten involved through bipartisan bills and letters aimed at spurring a collaborative process to determine if shared unlicensed use of all or a portion of the 5.9 GHz band is feasible. In February 2015 Senators Marco Rubio and Corey Booker reintroduced legislation, also introduced in the House, that would require the FCC to "provide additional unlicensed spectrum in the [5.9 GHz ITS band] under technical rules suitable for the widespread commercial development of unlicensed operations in the band."[64] And in September 2015, Senate Commerce Committee Chairman John Thune joined Senators Rubio and Booker – as well as industry representatives of both the auto industry and Wi-Fi advocates – in releasing nearly identical letters urging the FCC, DOT and NTIA to collaborate on testing to determine the "feasibility of sharing the valuable spectrum in the 5.9 GHz band to provide more spectrum for unlicensed uses like Wi-Fi."[65]

DSRC Technology and Channelization

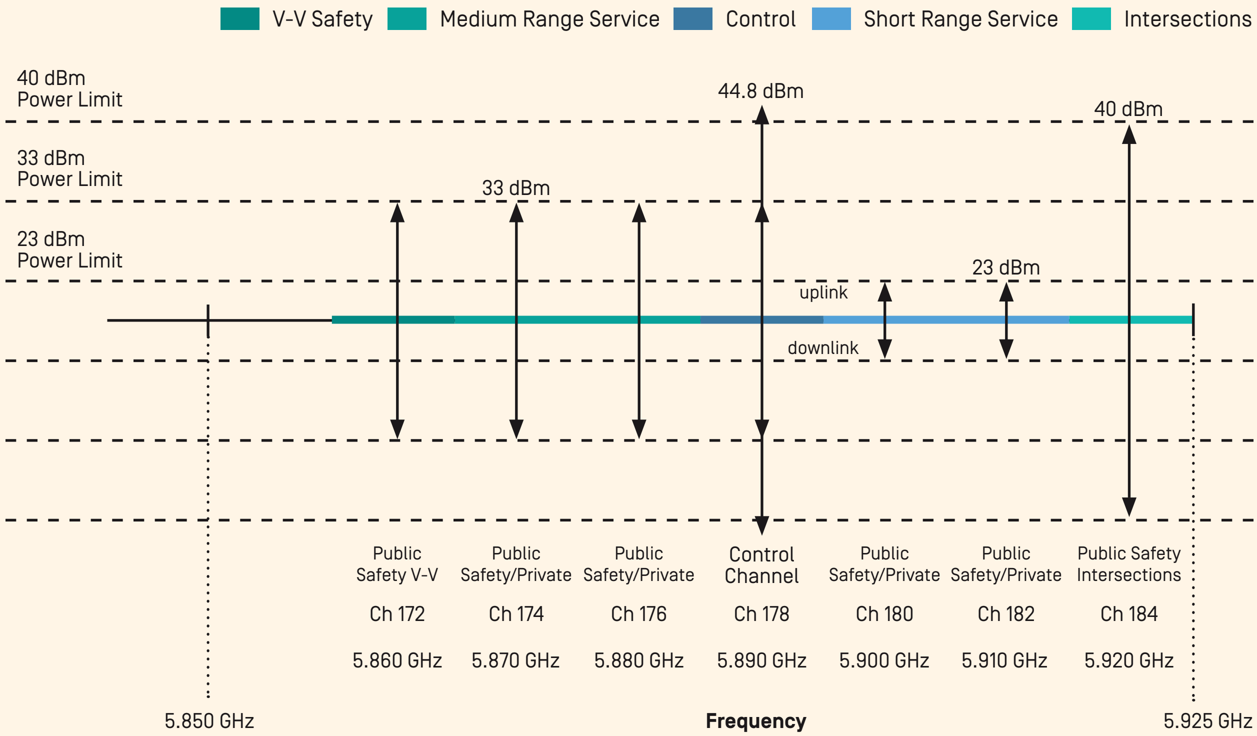
Today DOT and the auto industry publically tout DSRC technology primarily as a way to warn drivers of potential accidents, particularly with respect to vehicles outside the driver's direct field of vision. Studies testing driver acceptance found that drivers respond favorably in general to crash avoidance warnings.[66] Nevertheless, questions remain about the best mix of technologies – since driver assist sensing technologies have similar capabilities and are already available – and about how much spectrum must be reserved exclusively for the auto industry in order to yield promised public safety benefits. For example, auto companies want to retain near-exclusive use of the full 75 megahertz, without an auction and at no charge, but most of it would be used for commercial applications unrelated to safety. Furthermore, these non-safety applications are already being delivered today over general-purpose wireless networks (e.g., cellular and Wi-Fi). There are also questions about whether a technology designed for a different technical era is really best suited even for its primary safety mission.

The specific applications and services that would operate on DSRC channels have evolved over time. When ITS America initially petitioned the FCC for a dedicated band of spectrum, it emphasized non-safety services such as navigation assistance, in-vehicle signage, driver advisories, toll collections and fleet management for commercial enterprises.[67] Today the focus of DSRC technology, at least for DOT and its safety agency, NHTSA, has shifted to very narrowband V2V signaling applications designed to warn drivers of impending vehicular hazards and thereby avoid accidents before they occur. However, as discussed further below, real-time safety applications require 10 to 30 megahertz, raising questions about whether the remainder of the band will be intensively used by DSRC non-safety applications and, if so, why this should take priority over similar and potentially competing unlicensed operations.

In 2006 the FCC amended the ITS band's service rules to facilitate DSRC's development as a platform for separate safety and non-safety applications.[68] The band's 75 megahertz of spectrum is divided into seven channels of 10 MHz each and a 5 MHz buffer at the bottom of the band (from 5850 to 5855 MHz) that separates DSRC from the adjacent U-NII-3 band below. The Commission designated Channel 172, located at the bottom of the band (5855 to 5865 MHz), exclusively for V2V safety and crash avoidance communication. The FCC also designated Channel 184, located at the very top of the band (5915 to 5925 MHz), exclusively for higher-power, longer-distance public safety applications (such as communication from and between first responder vehicles for, e.g., intersection collision mitigation). Channel 178 (5885 to 5895 MHz), in the middle of the band, is reserved as a control channel to facilitate switching between applications on the non-safety-of-life DSCRC channels (necessary since under NHTSA's proposal, a vehicle would have one of its two radios tuned at all times to the V2V safety channel).[69]

Figure 3

DSRC Spectrum Band Plan and Channelization



Source: Adapted from NHTSA, V2V Readiness Report (2014), p. 93.

Vehicle-to-infrastructure (V2I) services are a related, but distinct, field of DSRC technology, one where onboard systems communicate with sensors installed along roadways or at intersections. But V2I is at a far more preliminary stage of development than V2V.[70] NHSTA's research and pending rulemaking concerning a DSRC mandate is focused entirely on V2V safety technology. Any mandate concerning the use of DSRC for vehicle-to-infrastructure (V2I) communication is beyond the scope of the agency's proceeding and, with certain exceptions, beyond its authority to mandate or to regulate.[71]

Even if DOT had the authority to mandate the use of DSRC for V2I applications (e.g., exchanging information with traffic signals or roadside signage), implementation would face many more obstacles and take far longer than the minimum 15-to-20 years it will take to fully implement a V2V mandate.[72] V2I would require the installation and maintenance of standardized roadside equipment and other infrastructure along hundreds of thousands of miles of roadway controlled by thousands of separate federal, state, county and municipal government jurisdictions.[73] This would be enormously expensive – and an unlikely candidate for Congress to impose as an "unfunded mandate" on already fiscally-constrained local governments. And even if the federal government appropriated tens of billions of dollars to the 50 states, it's not clear that V2I would be the top local priority for traffic safety and efficiency. For example, many urban areas might decide that the funds are better spent to reduce congestion by adding lanes to major roads.

DSRC crash avoidance technology could provide many benefits in a decade or two if NHTSA mandates its adoption for V2V signaling. Nevertheless, it remains important for policymakers grappling with the question of whether DSRC systems can share all or at least part of the 5.9 GHz band with Wi-Fi and/or other low-power unlicensed technologies to consider the broader context in which a V2V mandate would be implemented:

First, there is a critical distinction between DSRC safety-of-life applications and DSRC informational applications. DSRC research and testing has focused on accident prevention technology. But DSRC advocates cite other informational applications that are, while useful, not directly involved in preventing accidents, or do not involve real-time communication. Non-safety DSRC applications are likely to include in-car information that enables turn-by-turn directions, traffic congestion and weather alerts, the ability to make wireless payments at gas stations or parking garages, or to chat between vehicles or view advertisements from roadside vendors. In making spectrum allocations, it is important to identify and separate out the spectrum requirements for safety-of-life applications specifically. DSRC safety applications do not require a lot of spectrum bandwidth, whereas informational services require far more. Furthermore, most of the informational services DSRC technology is touted to deliver are already publicly available via smartphone applications and other mobile edge providers. And as ubiquitous, high-speed cellular and Wi-Fi connectivity increasingly give drivers and their passengers the ability to access any mobile app or service anywhere, the utility, efficiency and equity of an exclusive and free band of spectrum for duplicative and competing auto industry applications is rightly called into question.

Second, there are a growing number of alternative technologies that can also prevent motor vehicle accidents. DSRC is not the exclusive path to crash avoidance, but one of a number of rapidly evolving technologies that can prevent accidents. Increasingly sophisticated crash-avoidance radar, lasers (LIDAR), cameras, automatic braking, ultrasonic sensors, drowsiness detection and other onboard sensors make each individual car immediately more aware and capable of avoiding accidents regardless of how many other vehicles on the road are similarly equipped. These driver-assist safety applications are already available as options, and as noted above, will soon be standard features in the majority of new model cars.[74] Ultimately, the future is likely to be dominated by a mix of semi- and fully-autonomous vehicles that use a combination of driver-assist technologies to automatically sense-and-avoid accidents. Although fully autonomous vehicles have not hit the market, companies including Google have already extensively road-tested autonomous vehicles, and the new Tesla Model S includes an "autopilot" system integrating cameras, radar, GPS and ultrasonics.[75] None of these driver-assist or autonomous car safety systems use or rely on DSRC.

In addition, the crash-avoidance technologies available along roadways and in drivers' pockets are also evolving rapidly. For example, the use of Bluetooth-equipped traffic lights by cities has long-term potential not only for providing real-time data back to city administrators, but also for sharing traffic information with vehicles through the Bluetooth and/or Wi-Fi connectivity already built into drivers' smartphones and cars. Wi-Fi Direct is another example of a wireless technology that can offer applications comparable to DSRC, but by leveraging wireless connections and devices (e.g., smartphones) that are already ubiquitous for other purposes – and carried by drivers and pedestrians alike.[76]

B. A Critical Distinction: Safety of Life and Informational DSRC Applications

DSRC technology has the potential to support a range of future applications and services. The Department of Transportation is rightly focused on V2V signaling as a means of harnessing DSRC to automate crash avoidance warnings. In August 2014 NHTSA released an advanced notice of proposed rulemaking (ANPRM) seeking comment on whether it should issue a mandate requiring V2V safety technology in all future passenger cars and light trucks.[77] NHTSA has not proposed extending DSRC safety applications to V2I, which is not within its jurisdiction and would be dependent on widespread infrastructure builds by state and local governments across the nation.

However, even if NHTSA adopts a V2V mandate, most of the ITS band would not be used for real-time crash avoidance or public safety purposes. From the outset, the auto industry has emphasized other potential DSRC applications in addition to real-time V2V safety. According to the industry, these non-safety-of-life apps range from navigation assistance (e.g., turn-by-turn directions), mobile tolling and parking payments, real-time traffic and weather updates, in-vehicle displays of roadside signage, among others.[78] These applications are clearly useful, but are also generally "ancillary" to the core safety-of-life applications that narrowband DSRC signaling enables on a single V2V safety channel.[79] Moreover, these non-safety applications are already available to millions of drivers on the road today using smartphones through systems that include Apple CarPlay, Android Auto, Mirrorlink and OEM-designed integrations of cellular connectivity.

Real-time V2V safety-of-life applications are inherently narrowband and designed to require only a fraction of the 75 megahertz of spectrum currently allocated for ITS and DSRC technology. Basic safety messages (BSM) are the central component of crash avoidance technology. These are simple transmissions, broadcast in all directions by an onboard DSRC antenna, that include information on the vehicle's speed, heading, braking status, and other details on its current state. Safety of life applications require real-time transmission of small amounts of data on the order of 100 to 500 bytes of information per transmission with a general latency requirement of 100 milliseconds or less.[80]

NHTSA and international regulatory bodies acknowledge the narrowband character of V2V safety communications, and emphasize that the real-time reliability of the BSMs communicated between vehicles is what's most critical.[81] When the FCC adopted the channelization plan for DSRC proposed by ITS America in 2003, it allocated one 10 MHz channel specifically to V2V basic safety messaging.[82] NHTSA has subsequently taken the position that crash-avoidance signaling (BSMs) must be limited to a *single dedicated 10 MHz channel* that is not shared with non-safety applications:

> Testing for DSRC will likely require procedures to establish both that the DSRC unit itself is able to receive and transmit the needed messages as timely as needed and without being compromised (recognizing that in the current design, **one radio will be used exclusively for sending and receiving BSMs**, while the other will be used to communicate with infrastructure and the security system), and that the BSM elements are accurate.[83]

Accordingly, the most comprehensive field testing of DSRC technology to date focused on the single-channel BSM-based safety services.[84] The current band plan identifies a separate DSRC channel at the very top of the 5850-5925 MHz band for public safety and first responder communications.

Non- safety-of-life, informational DSRC services will be required to operate on other DSRC channels and could have much higher bandwidth needs.[85] These services are wider-band, less delay-sensitive and typically premised on connectivity to the Internet or other external data sources.[86] NHTSA's pending rulemaking to decide whether to mandate DSRC technology as a standard feature in future vehicles has, rightly, focused on real-time V2V crash avoidance warnings. Although the auto industry would gain some competitive and financial advantage from free, exclusive access to interleaved spectrum for non-safety, informational DSRC applications (most of which are already available to consumers through smartphone and tablet apps) it's important to realize that these would operate on different service channels separate from BSM safety applications.

1. Safety-of-life Applications are Narrowband and Real Time

V2V safety-of-life applications rely on "basic safety message" (BSM) transmissions. BSM signals include information on speed, heading, braking status and other details on the vehicle's status. They are transmitted from onboard wireless antennas and broadcast out in a full 360-degree range around the vehicle. Sensors on neighboring vehicles pick up the signals. If the onboard system in any of these vehicles calculates that a collision is imminent, the driver is notified by visual, audible and/or tactile warnings (e.g., steering wheel vibration, or a windshield display). In the future, semi-autonomous safety systems could allow the car to automatically brake or swerve, even without the driver's involvement.

Table 1

Vehicle-to-Vehicle Safety Applications

Safety Application	Description
Forward Collision Warning	Warns the driver of an impending rearend collision with another vehicle ahead in traffic in the same lane and direction of travel.
Electronic Emergency Brake Light	Warns the driver of another vehicle that is braking hard farther up ahead in the flow of traffic. The braking vehicle does not necessarily have to be in the direct line of sight of the following vehicle, and may be obscured by other vehicles or weather conditions (e.g., fog).
Do Not Pass Warning	Warns the driver when a slowermoving vehicle, ahead and in the same lane, cannot be safely passed using a passing zone that is occupied by vehicles in the opposite direction of travel.
Left Turn Assist	Warns the driver of a vehicle intending to turn left in front of a vehicle traveling in the opposite direction if that vehicle is too close or not stopping.
Intersection Movement Assist	Warns the driver when it is not safe to enter an intersection due to high collision probability with other vehicles at controlled (with stop lights) and uncontrolled (with stop, yield, or no signage) intersections.
Blind Spot & Lane Change Warnings	Warns a driver before/during a lane change if the blind spot zone into which the driver intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction.
Control Loss Warning (CLW)	Host Vehicle broadcasts a controlloss notification (e.g., loss of control on ice) to surrounding vehicles. Vehicles receiving event notifications determine the relevance of the event and warn the driver if appropriate.

Sources: NHTSA, Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application; Tom Schaffnit, et al, Technical Appendix, Comments of the Alliance of Automobile Manufacturers and the Association of Global Automakers, ET Docket 13-49, May 28, 2013.

NHSTA believes that V2V signaling using DSRC can help prevent or mitigate many common causes of automotive accidents.[87] Automated safety messages could warn when a rear end, lane change, or intersection crossing crash is imminent. Table 1 (on opposite page) lists the major accident scenarios that V2V technology could help prevent. The goal of V2V communication is to ensure that the driver is aware of an impending situation the driver cannot yet detect (e.g., vehicles braking ahead) or is in danger of misjudging (e.g., left turn assist).

Although NHTSA acknowledges that most of these crash avoidance scenarios would be addressed as well by driver-assist technologies, such as vehicle-based sensors (e.g., radar, lidar, cameras), the agency identifies three safety applications "that the agency believes are enabled by V2V alone and not replicated by any current, known vehicle-resident or camera-based systems."[88] The three scenarios where V2V could be uniquely helpful are "intersection movement assist" (where it is unsafe to enter an intersection due to unseen approaching cross traffic), "left turn assist" (warning the driver not to turn in front of oncoming traffic), and "emergency electronic brake light" (alerting the driver that an unseen vehicle ahead is braking or rapidly decelerating, a warning particularly useful in fog or heavy rain).[89]

2. Non-Safety-of-Life Applications are Not Real Time and Largely Redundant

The primary focus of DSRC technology is safety. But DSRC connectivity is intended to provide drivers and their passengers with other non-real-time and non-safety services as well. When initially proposed and allocated in the late 1990s, the auto industry pitched DSRC's potential to usher in a new era of "connected cars." When the FCC originally allocated 75 megahertz to the auto industry more than 15 years ago, it certainly sounded cutting edge to envision DSRC connectivity delivering a host of informational services to drivers that would provide turn-by-turn directions, improve traffic flow, provide in-vehicle displays of signage, send driver notification advisories (e.g., bad weather or construction ahead), and fleet management for commercial enterprises.[90] DSRC advocates continue to point to similar information services, such as mobile tolling or eco-friendly driving guidance, to justify maintaining exclusive access to 75 megahertz of spectrum.

Needless to say, mobile technology has made radical advances since 1999. Today most cars on the road are already "connected." But that connectivity is provided by commercial cellular and/or Wi-Fi networks that power an innovative and constantly evolving variety of competing cloud-based applications to the driver's (or passenger's) smartphone or tablet. Vehicles themselves are increasingly becoming "smart" by integrating this same cellular and/or Wi-Fi connectivity to cloud-based applications and the wider Internet. AT&T, for example, added 1 million connected car subscribers during the second quarter of 2015.[91]

Clearly, the rise in mobile phone technologies and Internet technologies has cannibalized some of the purported benefits of DSRC. Just eight years after Apple introduced the iPhone in 2007, two thirds of American adults own a smartphone, including 85 percent of those aged 18-29.[92] The smartphone application market in particular has provided consumers with most of the same services that safety-ancillary DSRC applications were initially envisioned to provide. Individuals today can get real-time information updates via apps on their smartphones. Not only are smartphones and cellular networks nearly ubiquitous, but so are apps connected to cloud-based services that can crowd source real-time data without a new nationwide infrastructure build out (as DSRC must, since without roadside backhaul DSRC itself offers no connection to the Internet). Although DSRC could conceivably prove useful for collecting and uploading V2V signaling data via cellular or Wi-Fi networks to the cloud (e.g., to enrich the data used to map traffic flows or improve navigation services such as Waze or Google Maps), there is no clear rationale to prioritize these applications with an exclusive allocation of spectrum to a single industry segment (automakers).

Table 2

List of Potential DSRC Informational, Non-Safety Applications

DSRC Application	Description	Status
Electronic Tolling	Wireless payment of road tolls	Already widespread using 900 MHz unlicensed spectrum
Electronic Parking	Wireless payment for parking	Already available via cellular or WiFi
Traffic Updates	Real-time updates on area traffic conditions	Already widely available as mobile app via cellular or WiFi (e.g., Waze, OnStar, Google Maps)
Traveler Information & Navigation	Provide driver with detailed turn-by-turn directions to a final destination	Already widely in use as mobile app via cellular or WiFi (e.g., Google Maps, Waze)
In-Vehicle Signage	Provide driver with in-vehicle display of roadside signs	Not real-time: connectivity could be cellular or WiFi
Signal Phase and Timing Notifications for Non-Safety Applications	Inform drivers of traffic lights status and a timer on how long the current signal state will last	Not real-time: connectivity could be cellular or WiFi (depends on future local public infrastructure buildout)
Environmental Apps: Eco-Driving Tips	Provide driver with recommendations on driving behavior to improve fuel efficiency, reduce emissions	Not real-time: connectivity could be cellular or WiFi
Driver Notifications	Notify driver of approaching congestion, accident, severe weather, hazardous road conditions, construction	Generally available now, or could be, via mobile apps using cellular or WiFi connectivity

Sources: Comments of the Alliance of Automobile Manufacturers, Inc. and the Association of Global Automakers, Attachment 1, slide 7, p. 74. May 28, 2013; VII Consortium. 2009 test report. page 12. ITS America petition 1997.

As Table 2 illustrates, the combination of smartphones and 4G/Wi-Fi networks fuel a rich mobile ecosystem of alternative sources for the same functionality as DSRC's informational and "safety ancillary" services. The most obvious example is navigation assistance, both static (turn-by-turn directions) and dynamic re-routing around local congestion or accident bottlenecks. Pew Research reports that "67% of smartphone owners use their phone at least occasionally for turn-by-turn navigation while driving, with 31% saying that they do this 'frequently.'"[93] A DSRC-based service clearly would be duplicating and competing with what the market is already providing. Applications such as Waze, TomTom and Google Maps offer users not only mapping and directions (based on the GPS built into smartphones), but also real-time updates on traffic conditions, and notifications on accidents, construction, lane closures and weather.[94]

Sources: WAZE, a free mobile app, provides turn-by-turn navigation and crowdsources a variety of driver-assist information.

Many of these services are based on crowdsourced data generated by smartphones using apps that report location, direction and speed of individual vehicles to the nearest cellular access point, generating real-time data on traffic conditions. Transportation researchers have called crowdsourced traffic data by smartphone apps like Waze a "revolution" and a field poised for rapid innovation.[95] Indeed, many analysts view crowdsourced smartphone data – not data from hypothetical and scattered V2I roadside units – as a more viable source of information than DSRC as aggregated smartphone data leverages an already widely-deployed technology. Any new DSRC-based technology would be limited to new cars and areas where government shoulders the expense of installing roadside sensor systems.[96]

Mobile payment for parking is also increasingly common. Once again, smartphones are central. Residents in a growing number of U.S. cities can locate a vacant parking space, or pay for parking via smartphone applications. Even traditional mobile road tolling has seen advances since the FCC's initial DSRC spectrum allocation. Since 1999 an increasing number of states have adopted E-Z Pass as an interoperable standard for mobile tolling using DSRC in the 900 MHz unlicensed band, a low-frequency allocation with far better propagation characteristics that is also used by cordless phones, electric utilities (to read smart meters) and other purposes. Indeed, as Harvard Law Professor Yochai Benkler observed in his study of the economics of shared spectrum bands, the more open and flexible nature of the 900 MHz band was important to the wider adoption of mobile tolling technology:

> [T]he ubiquity of 900 MHz devices and the scope of products designed for that range made deployment of simpler, less expensive and versatile devices for toll collection follow a path that utilizes the ISM [unlicensed] band rather than the more protected, but less versatile, 5.9 GHz dedicated band.[97]

Of course, the auto industry has long viewed vehicle-based mobile apps, devices and data as a source of potential future revenue. Exclusive use of 75 megahertz of spectrum would support additional DSRC informational services, services which require more channels and bandwidth than safety-of-life DSRC applications.[98] But the mobile networks that flourished as DSRC floundered already offer consumers – whether or not they are in a car – ubiquitous access to mobile data and a diverse ecosystem of apps, many of which are free. Irrespective of DSRC, mobile connectivity will only increase further as 5G networks are developed and Wi-Fi becomes more and more accessible. Cable companies are building out large networks of Wi-Fi hotspots in urban areas, including hundreds of thousands of access points in public areas that could readily include highway corridors and other major roadways. Mobile carriers themselves are leveraging Wi-Fi technology and incorporating it into their network architecture in order to add more capacity to their network, a development known as "heterogeneous networks" (or "hetnets").

Consumers might pay more for certain car-based apps, which might some day operate from a deeper pool of V2V data. But that hypothetical opportunity appears a shaky rationale for the FCC to give one industry virtually exclusive use of more spectrum than is needed for real-time auto safety, blocking Wi-Fi, the technology that would be the auto industry's competitor for delivering non-safety services.

C. Alternative Safety Technologies: Will DSRC be Relevant by the Time it's Viable?

1. The Long Road to DSRC Adoption

DSRC has the potential to improve automotive safety and reduce accidents compared to safety technology currently built into cars. However, policymakers must also consider whether alternative technologies can meet these goals faster (in less than 15-to-20 years or longer) and more effectively (through automation).

V2V signaling only works to prevent accidents when all or at least most other vehicles have DSRC installed and operating.[99] NHTSA itself acknowledges V2V will not be viable without a regulatory mandate.[100] More critically, even if NHTSA adopts a regulatory mandate during 2016, the agency projects that it could take decades before a critical mass of V2V adoption is achieved. In the V2V Readiness Report, NHTSA explained that ubiquitous adoption of DSRC could not only take more than 30 years, but until a critical mass is achieved, it may not be possible to determine how effective it will be:

> Even if the market drives faster uptake by consumers of aftermarket devices (if, for example, auto insurance companies offer discounts for installing the devices), ... *it will still take 37 years before we would expect the technology to fully penetrate the fleet.* As a result, full knowledge of how different aspects of the V2V system perform ... may be delayed. ... The data collected during the Safety Pilot Model Deployment provide an indication of functional feasibility ... in effect, whether the prototypes and the system worked, but not necessarily how well they worked.[101]

> **DSRC has the potential to improve automotive safety and reduce accidents compared to safety technology currently built into cars. However, policymakers must also consider whether alternative technologies can meet these goals faster and more effectively.**

The agency's ANPRM does not specify when DSRC systems would be required in all new cars sold, but its V2V Readiness Report implicitly assumed (in 2014) that the base year for such a mandate would be 2020.[102] The existing motor vehicle fleet (more than 270 million cars, trucks and motorcycles) would generally lack DSRC technology until replacements are purchased. It will likely take 15-to-20 years on average for the nation's vehicle fleet to completely turn over.[103] In theory, drivers choosing to install 'aftermarket' DSRC devices could speed up this timeline. However, DOT estimates that aftermarket systems, not including installation, could cost as much as $1,000 initially.[104] Since consumers would have little incentive to bear this cost until the vast majority of vehicles on the road are equipped – and because many could still not afford the expense – substantial government subsidies would likely be needed to achieve a critical mass of adoption prior to 2030.[105]

NHTSA also acknowledges that "V2V devices in various vehicles may not be able to support all the safety applications."[106] Although NHTSA is proposing to mandate DSRC, the ANPRM states that "NHTSA currently does not plan to propose to require specific V2V-based safety applications."[107] The agency proposes leaving the actual safety applications and crash avoidance scenarios to be addressed to the discretion of individual automakers and market forces. And although NHTSA states that "the overall potential of V2V and the number of crashes prevented and lives saved is highly dependent on the number of safety applications deployed [and] the penetration of those applications in the fleet," it nevertheless concedes that even many years after a V2V mandate, "a safety application as initially developed by an OEM or supplier may only address a subset of the pre-crash scenarios."[108]

Vehicle-to-Infrastructure

Finally, as mentioned earlier, the potential NHTSA mandate and multi-decade adoption estimate is concerned solely with V2V technology. The agency is researching but not formally considering any requirements or regulations related to the use of DSRC with roadside infrastructure. This is notable considering that, based on auto industry assertions, DSRC that connects "Roadside Units" (RSUs) to vehicles were a major focus of the FCC's spectrum allocation and licensing scheme in the Report and Order adopted in 2003. Yet V2I remains at a much earlier stage of development than even V2V, and as noted above, faces far greater challenges. V2I requires interoperable infrastructure deployed along at least primary roadways. Building, installing and maintaining DSRC infrastructure would be enormously expensive. Costs and responsibilities would need to be divided between the federal government (presumably for the 1 percent of U.S. road miles that comprise the Interstate Highway System) and thousands of state, county, and municipal jurisdictions.

In a highly skeptical report to Congress last September 2015, the GAO concluded there is "a lack of state and local resources to develop and maintain V2I systems," stating:

> Because the deployment of V2I technologies will not be mandatory, the decision to invest in these technologies will be up to the states and localities that choose to use them . . . However, many states and localities may lack resources for funding both V2I equipment and the personnel to install, operate and maintain the technologies. . . . [T]he national Cooperative Highway Research Program [NCHRP] noted that . . . current state budgets are the leanest they have been in years. Furthermore, traditional funding sources, such as the Highway Trust Fund, are eroding, and funding is further complicated by the federal government's current financial condition and fiscal outlook.[109]

Local transportation budgets are tight and there is already an enormous unfunded need to repair and maintain current roads and bridges. Installing expensive new transportation infrastructure would introduce an entirely separate and contentious political debate that at least so far has received little attention or support.

2. Driver Assist Sensing Technologies

DSRC technology envisions a future where all cars can "hear" each other through wireless signaling technology. But imagine futuristic cars that could instead "see" not only other vehicles, but also far more of the road and its surrounding environment, including pedestrians, bicycles and obstacles. These cars would use radar and laser sensing systems to alert drivers to obstacles, such as a car in the driver's blind spot; use cameras to monitor road lane markings and trigger keep-lane corrections; or even use internal cameras to alert drowsy or distracted drivers. All these technologies, and more, are already available in many vehicles and, as noted above, DOT recently announced that ten major automakers representing nearly 60 percent of U.S. car and light truck sales have agreed to make sensing-based automatic emergency braking systems standard equipment in all new vehicles.[110]

The automotive industry is developing a host of such "driver assist" safety technologies that are not in any way reliant on the deployment or mass uptake of DSRC technology. Sensing-based applications rely on unregulated light waves as well as radar systems that use a different unlicensed band at 76-77 GHz.[111] Each car equipped with driver-assist technologies immediately promotes crash avoidance for the car using it and simultaneously reduces risk for other cars (whether or not they are equipped). Radar, lasers (LIDAR) and camera-based car safety systems sense other vehicles on the road and provide crash avoidance warnings that duplicate most of the safety-of-life applications that V2V/DSRC promises to deliver. These car-based sensing technologies are analogous to enhanced human senses that "see" in every direction simultaneously and at potentially greater distances.

Driver-assist technologies are specifically designed to sense and prevent rear end crashes ("forward collision avoidance") and to provide lane-change warnings and basic intersection movement assistance. Car-based sensing can be combined with automatic braking or maneuvering, or the system can simply alert the driver, as it is anticipated V2V will do. Crash avoidance systems based on radar and cameras have the advantage of being autonomous, warning their driver of potential accidents regardless of whether or not the other vehicle has any additional safety technology. And unlike DSRC technology, today consumers can already purchase cars equipped with radar and camera crash avoidance technology. Indeed, Ford has announced it intends to make such safety systems available on most of their vehicles by 2019, including a "Pre-Collision Assist with Pedestrian Detection" application.[112]

The forward collision warnings and automatic braking systems that will soon be standard equipment in most new vehicles provide an example of how driver-assist technologies could have a large and immediate impact. NHTSA identifies rear end collisions as the most common and costly crash scenario that technology could mitigate or eliminate. It represents nearly one-third of all collisions, injuries and property damage from accidents each year.[113] This makes forward collision warnings the most impactful DSRC safety application. However, a report issued in 2015 by the National Transportation Safety Board (NTSB) highlights research showing that camera- and sensor-based crash avoidance systems are already having a measurable effect in preventing real world accidents.[114] As described further in the next section, Google's autonomous cars, incorporating this same technology, have driven more than a million miles without a single front-end collision (or any collision not the result of human driver error).

Radar- and camera-based intersection safety applications have the added capability to warn drivers about pedestrians, cyclists, lane closures and any other visible traffic hazard, as well as other vehicles without crash avoidance technology. While DSRC does permit vehicles to "hear" other vehicles around a blind curve or corner, V2V will typically not enable vehicles to "see" other hazards. This is significant since collisions with non-vehicle fixed and mobile obstacles represent more than 30 percent of all collisions, 28 percent of all injuries, and more than 50 percent of all traffic fatalities.[115] Pedestrians and cyclists, for example, are unlikely to carry DSRC transmitters, making a radar- and camera-based system a more flexible and comprehensive approach. And although NHTSA speculates that pedestrians could carry smartphones with apps that broadcast a DSRC signal to surrounding traffic,[116] it does not speculate about how vehicles would distinguish pedestrian smartphones from the smartphones of passengers in surrounding vehicles, including cars that might be parked just a few feet from the pedestrian about to dash into traffic.

The National Transportation Safety Board's June 2015 report strongly recommended that NHSTA make sensor-based crash avoidance technology mandatory.[117] The report warns that an effective implementation of V2V using DSRC technology is so far off that a hybrid approach that relies initially on driver-assist sensing technology, including radars and cameras, would be far more effective:

> It may be an additional two to three decades more before the majority of the passenger and commercial fleets become connected [with DSRC]. Given this timeline, an alternative active safety system is necessary until the [DSRC/V2V] technology matures. Vehicle-based [sensing systems] provide just such an alternative for two significant reasons: (1) they are immediately available and can prevent collisions and save lives today; and (2) they

Table 3

Driver Assist Technologies and Sample Models

Feature	Tesla Model S[i]	2016 Mercedes E350 Sport Sedan[ii]	2015 Toyota Camry[iii]	2016 Mazda CX 5[iv]	2016 VoXC 90[v]
Automated Emergency Braking	✓	✓	✓	✓	✓
Distance Monitoring	✓	✓ (Tesla Adaptive Cruise Control–TACC)[vi]	✓	✓	✓
Forward Collision Warning/Braking	✓ (Forward looking camera)	✓	✓	✓	✓
Rear Alert System		✓ (Rear-view cameras)	✓		✓ (Rear-view cameras)
Lane Keep Assist	✓	✓	✓	✓	✓
Left Turn Assist					✓
Blind Spot Assist	✓	✓	✓	✓	✓
Intersection Cross Traffic Assist		✓	✓ (Rear cross traffic)	✓ (Rear cross traffic)	✓
Pedestrian Recognition Assist/Braking	Possibly[vii]	✓	Announced for 2017 models[viii]		✓
Other		Attention Assist, Pre-Safe (prevents rollovers)			Reversible belt retractor (ERR) tightens seat belt before collision

i See "Model S Specifications," Tesla Motors, available at http://www.teslamotors.com/support/models specifications.
ii See "2016 EClass," Mercedes Benz, available at https://www.mbusa.com/vcm/MB/DigitalAssets/pdfmb/brochures/MY16_E_SW.pdf.
iii See "2016 Camry: Safety Systems," Toyota USA, available at http://www.toyota.com/camry/#!/features/safety systems.
iv See "2016 Mazda CX-5 Specifications," Mazda USA, available at http://www.mazdausa.com/MusaWeb/displayPage.action?pageParameter=modelsSpecs&vehicleCode=CX5
v See "Volvo XC-90 Effortless Safety," Volvo, available at http://www.volvocars.com/us/cars/new-models/all-new-xc90/safety; see also "Intellisafe," Volvo, available at http://www.volvocars.com/us/about/our-innovations/intellisafe.
vi See "Traffic-aware Cruise Control (TACC) – Good & Bad Details" (Jan. 11, 2015), Tesla Forums, available at http://my.teslamotors.com/forum/forums/trafficaware-cruise-control-tacc-good-bad-details.
vii See "Active Pedestrian Alert – Elon's Response" (28 Jun. 2013), Tesla Forums, available at http://my.teslamotors.com/it_CH/forum/forums/active-pedestrian-alert-elons-response.
viii See Clifford Atiyeh, "Next-Gen Toyota Pre-Crash, Pedestrian-Detection Systems to Debut on 2016 Lexus RX," Car and Driver (Dec. 8, 2014), available at http://blog.caranddriver.com/next-gen-toyota-pre-crash-pedestrian-detection-systems-to-debut-on-2016-lexus-rx/.

> address the limitations of the [connected vehicle] technology.[118]
>
> ...Warning alerts or autonomous braking are additional functions that would have to be integrated within a vehicle—functions that are already part of vehicle-based forward [sensing systems].

As noted above, NHTSA maintains that V2V signaling is uniquely able to address three very costly crash scenarios: left turn assist, intersection movement assist, and emergency electronic brake light notification (which provides a warning that unseen vehicles ahead are rapidly decelerating). Yet alternative technologies are being developed for these safety applications as well. Mercedes has reportedly developed a radar system that can track and provide emergency brake warnings with respect to not just the vehicle directly in front of the driver, but also for a second vehicle located further ahead and not immediately in the driver's line of sight.

Finally, some DSRC advocates warn that radar- and camera-based safety technologies are susceptible to line-of-sight barriers and certain weather conditions. In discussing its program to develop autonomous car technology, Mercedes Benz has stressed that radar systems are reliable in all drivable weather conditions. Industry analysts also observe that if the weather conditions are bad enough to disable radars and cameras (e.g., driving rain or heavy snowfall), the vehicle should not be on the road in any case.

DSRC technology has similar performance limitations of its own, due in large part to the poor propagation characteristics of high-frequency spectrum. The 5.9 GHz band has limited propagation without clear line of sight transmission. In initial DSRC testing conducted in 2009, the Vehicle Infrastructure Integration Consortium noted at the time that "DSRC range is heavily dependent on line of sight."[119] Other tests reported that DSRC's effective range is closer to 50 meters than to the 300-meter range often claimed by auto industry advocates.[120]

3. Autonomous Vehicles

Google, Tesla, Mercedes and some other automotive innovators do not view the future of the driver-assist sensing technologies described above as limited to better and faster warnings to drivers. These companies are far along in developing and testing technologies that replace human drivers, either partially or entirely, with sensor- and processor-driven autonomous vehicle control systems.[121] Autonomous vehicles and the more advanced 'smart car' technology they incorporate are already on the roads – albeit primarily as beta test vehicles, or with the caveat that drivers should remain engaged.

In October 2015 Tesla announced a new "autopilot" feature for its Model S that uses its banks of sensors and cameras to "steer, change lanes and drive at highway speeds with little or no help from the human behind the wheel."[122] Google's fully autonomous cars have already logged more than a million test miles on public roads with only a handful of accidents – all of which were due to human error and none because the self-driving car was at fault.[123] Google's typically ambitious goal for driverless cars is not only to almost entirely eliminate auto accidents, saving millions of lives, but also to save society the millions of hours of lost time spent each year driving when, like the wealthy, we could all have chauffeurs (albeit of the robot variety). And even General Motors views autonomous vehicles as an "opportunity to be a disrupter" and will test autonomous Chevy Volts by late 2016, allowing employees to summon the car using a mobile app for drives around its corporate campus.[124]

Autonomous cars take existing crash avoidance sensor technology like radars and cameras and combine these with powerful onboard processors to fully automate the decision-making and response process. Instead of providing a proximity notification warning – and expecting a driver to respond to a steering wheel vibration or flashing light – a fully autonomous vehicle system responds on its own to apply the brakes, gas, or steer as needed. Google reports that the sensor systems on its prototype driverless cars have a range of up to 200 yards and can detect and track multiple targets including all other vehicles, cyclists and pedestrians, as well as recognize and respond appropriately to safety-related scenarios, such as construction zones or passing emergency vehicles.

Since it's not clear that all or even most drivers will want a fully autonomous vehicle, Toyota has launched an artificial intelligence research project aimed at developing "intelligent" cars that will act as a "guardian angel," monitoring the driver's behavior and intervening with autonomous controls (braking, maneuvering, warnings) only to correct mistakes or to avoid crashes when needed. In essence, Toyota's vision is an A.I. system that augments the driver-assist technologies that are already emerging as standard safety options – such as pedestrian and bicycle detection, lane-departure warnings and automated lane-keeping systems. In Toyota's system, drivers remain in control while gaining the benefits of the sort of technologies that Google is marshaling to replace the driver entirely.[125]

While Telsa is the only automaker with a semi-autonomous driving system in 2016 model cars, other automakers report having autonomous vehicles in development and plan to roll out initial models in the next few years.[126] McKinsey projects that consumers will not adopt fully autonomous, self-driving vehicles on a large-scale basis until 2030 or beyond.[127] However, it is worth noting that this projection puts fully autonomous vehicles on a faster time frame that the 20-to-37-year timeline for ubiquitous adoption of V2V/DSRC technology.[128]

In sum, while DSRC has the potential to enhance crash avoidance, it will be at best a very narrowband adjunct to the more immediately effective and ever-more-sophisticated sensing and autonomous vehicle technologies already hitting the streets. However important its role in auto safety will be 15-to-20 years from now, DSRC's core functionality is premised on a single 10 megahertz basic messaging channel that does not preclude sharing substantial portions of the overall 75 megahertz, most of which at best be used to support non-real-time and non-safety-of-life applications.

GLOBAL DEVELOPMENTS

International harmonization of spectrum policy encourages technology to be interoperable and compatible across borders. This facilitates global markets for new technologies, reducing equipment costs more quickly by increasing the scale of production. This section looks at how the European Union and Japan have allocated spectrum for DSRC, as well as the distinctions drawn between real-time safety and non-safety-of-life applications riding on DSRC.

In short, both the EU and Japan have allocated considerably less spectrum specifically for safety-related DSRC systems. In Europe, regulators concluded that two DSRC channels (20 megahertz) are sufficient for "time critical road safety applications" – and another 10 megahertz for non-critical but safety-related applications. This is not surprising considering that NHTSA has proposed requiring that all basic safety messaging (BSMs) for V2V must be transmitted on a single 10 megahertz real-time safety channel. As NHTSA reports, "[t]he EU allocation calls for the 5.875-5.905 MHz band to be designated for safety-related ITS functions with three 10 MHz channels, including the possibility of two additional channels being granted in the future. No control channel exists in the EU approach."[129]

Japan has taken an entirely different approach – and uses an entirely different band of spectrum. Japan has allocated 80 megahertz of spectrum from 5770 to 5850 MHz – which coincides with the adjacent unlicensed band (U-NII-3) in the U.S. The Japanese allocation ends at the point at which the U.S. allocation for ITS/DSRC begins (5850 MHz). Japan is also focused primarily on deploying ITS roadside units along its highways, for automated tolling and other "hotspot" services (which in the U.S. are deployed on 900 MHz unlicensed spectrum), unlike the initial U.S. focus on pursuing universal V2V signaling. These tolling and related operations operate on low-band spectrum below 1 GHz.

European Union

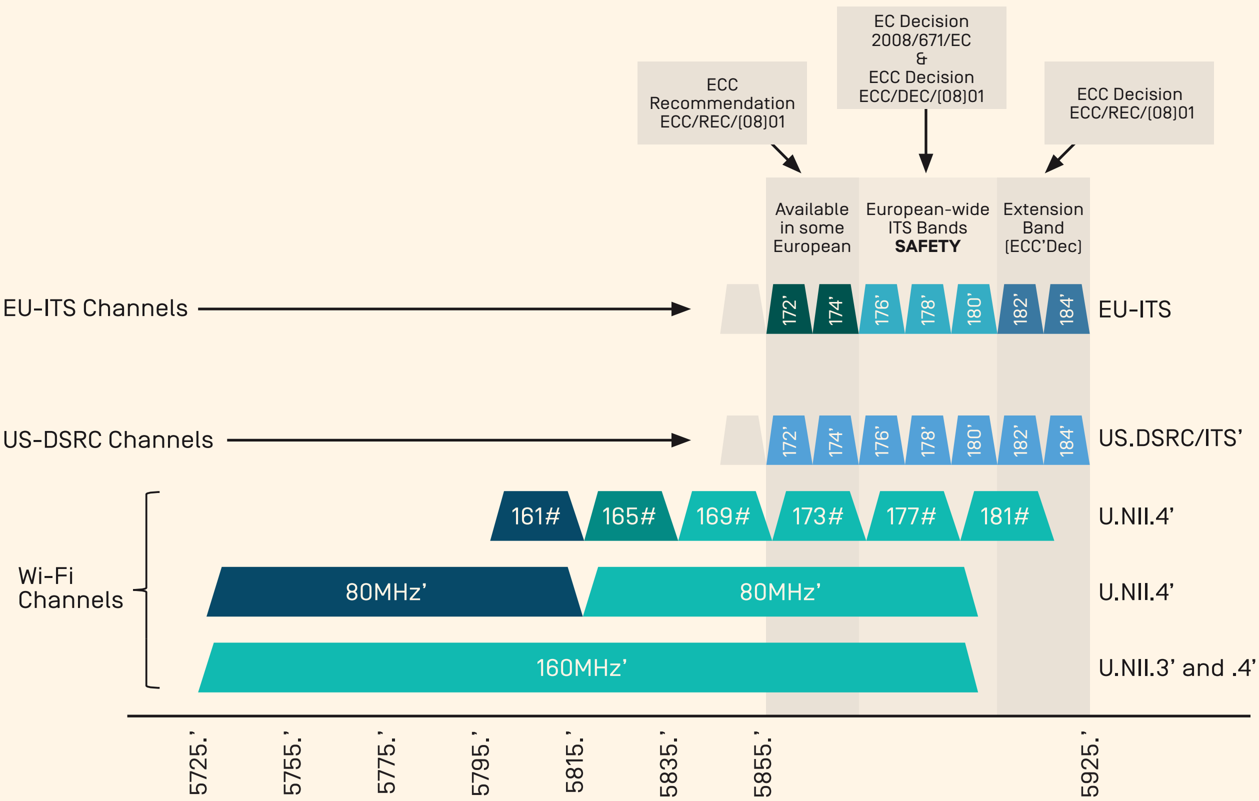
In 2008 the Electronic Communication Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) issued decisions allocating the spectrum band from 5855 to 5925 MHz for potential ITS use.[130] While this is nearly identical to the current U.S. allocation, there are notable differences. The CEPT makes a clear distinction between the allocation for critical safety and non-safety ITS services. "Traffic Safety Applications" (including non-critical but safety-related applications) are specifically allocated a 30 MHz block in the middle of the band, from 5875 to 5905 MHz.[131] The bottom 20 MHz (5855 MHz to 5875 MHz) is specifically allocated for "non-safety applications" for ITS on a shared basis with license-exempt devices. In fact, the 150 MHz immediately below 5875 MHz – which includes the spectrum corresponding to the lowest 25 MHz of the U.S. allocation for ITS (5850 to 5875 MHz) – is allocated for ISM (unlicensed) devices and a diverse array of Short Range Devices that use shared frequency bands on a license-exempt basis.[132] Finally, the top 20 MHz of the band (5905 MHz to 5925 MHz) is not actively allocated to ITS services, but instead is reserved and "to be considered for future ITS extension."[133]

The CEPT decision acknowledges that ITS safety applications do not require a full 75 MHz of bandwidth, stating:

> CEPT/ECC studies regarding the necessary spectrum requirements for road safety and traffic efficiency within the 5.9 GHz band based on accepted traffic scenarios with both IVC and I2V communication have confirmed that **a realistic estimate of the needed bandwidth**

Figure 4

European ITS Spectrum Allocation[134]



Source: Landsford, et al., "Final Report of DSRC Coexistence Tiger Team," IEEE (Mar. 9, 2015), at p. 25, available at https://mentor.ieee.org/802.11/dcn/15/11-15-0347-00-0reg-final-report-of-dsrc-coexistence-tiger-team-clean.pdf.

is between 30-to-50 MHz including 20 MHz of bandwidth for time critical road safety applications.[135]

In addition, as NHTSA acknowledges, the EU is not contemplating a V2V mandate and is pursuing a “market-driven” approach that does not emphasize V2V for critical safety signaling. Rather, it supports communication with infrastructure and other networks to enhance mobility and sustainability applications.[136] “While the EU has defined crash-critical safety applications as well, the priority in the EU is driver safety advisories (not safety-critical warnings), driver support messages (such as eco-driving), and commercial applications such as insurance,” NHTSA reports.[137]

Japan

Japan’s ITS spectrum allocation is not harmonized at all with the U.S. or Europe. Japan has assigned 80 MHz for connected car services in the band below 5850 MHz (from 5775 to 5805 MHz and 5815 to 5845 MHz), in what are the license-exempt ISM bands in the U.S. and Europe.[138] Japan also has a limited allocation for Advanced Safety Vehicle (ASV) functions of V2V and V2I in the 760 MHz band.[139] As NHTSA acknowledges, Japan is “appears likely to proceed with a two-band solution” that focuses, as in Europe, on vehicle to infrastructure communication.[140] And neither band corresponds to the U.S. allocation.

In addition to a non-overlapping spectrum allocation, Japan has taken an entirely different approach by deploying roadside units for tolling and other purposes. Although Japan has made significant strides in deploying vehicle-to-infrastructure (V2I) technologies, including 1600 ITS hotspots deployed along its roadways as of 2011,[141] V2V is on a slower track.[142] In addition to Japan’s initial focus on using DSRC at 760 MHz to facilitate wireless toll collection (as the U.S. has done using the 900 MHz unlicensed band), Japan’s ITS hotspots also “offer limited V2X safety capabilities, as well as mobility and convenience services.”[143] For example, Toyota announced in late 2014 that it would equip certain models with V2V systems that use spectrum in the low-band 760 MHz band to augment lasers, cameras and other driver assist safety technologies “to gather information that cannot be obtained by onboard sensors.”[144]

In sum, while there is some international coordination around spectrum allocations for ITS and the use of DSRC technology, major differences remain. Notably, although the U.S. auto industry still has no V2V deployments or standardized equipment, it remains ahead of the rest of the world in terms of a potential V2V deployment and the designation of real-time safety channels. Because the E.U. has already determined that 30 megahertz is sufficient for “time critical” crash avoidance communications, the U.S. could still shape a harmonized band that accommodates both V2V and shared use of at least a portion of the band with low-power unlicensed uses. Europe’s posture suggests that despite claims by DSRC advocates in the U.S., V2V and related safety-of-life applications do not require a full 75 MHz of dedicated and exclusive spectrum. It also suggests that some version of Qualcomm’s 2013 proposal to relocate safety applications to the upper portions of the band and allow Wi-Fi and DSRC spectrum sharing in the lower, non-safety portions of the band, is not only feasible but would improve the harmonization of international spectrum policy with respect to Europe.

THE NEW REGULATORY PARADIGM: GENERAL PURPOSE SHARING, NOT SPECIAL PURPOSE SILOS

Whether or not the auto industry's non-safety-of-life DSRC services are ever deployed and gain traction with consumers, the industry's insistence on excluding other technologies from the band is clearly problematic. The auto industry did not acquire its licenses via auction, and leaving most of the band's capacity essentially fallow for the indefinite future is distinctly inconsistent with FCC spectrum management principles adopted in the years since the original 1999 ITS allocation. It also runs counter to the Obama Administration's historic initiative to open underutilized bands for sharing to the greatest extent feasible. The admonition in the 2012 report and recommendations of the President's Council of Advisors on Science and Technology (PCAST) is as relevant for the 5.9 GHz band as it is for sharing underutilized Navy radar spectrum at 3.5 GHz:

> The incongruity between concern about a 'looming spectrum crisis' and the reality that only a fraction of the Nation's prime spectrum capacity is actually in use suggests the need for a new policy framework to unlock fallow bandwidth in all bands, as long as it can be done without compromising the missions of Federal users and ideally by improving spectrum availability for Federal users. [145]

As Julius Knapp, the chief of the FCC's Office of Engineering and Technology, stated in a speech last year, "the days of service-specific spectrum allocations are over – the Commission's flexible rules in both unlicensed and licensed bands obviate the need for allocations narrowly tailored to specific uses."[146] Knapp went on to note that dedicating spectrum exclusively for particular smart devices or machine-to-machine applications would waste limited resources. He also observed that although the 5.9 GHz band has been allocated for DSRC applications for 15 years, today automakers are advertising "connected vehicle" applications that rely on LTE cellular and Wi-Fi networks for wireless connectivity.[147]

The auto industry's defense of single-purpose allocations and command-and-control spectrum regulation is a throwback to the period that pre-dated the industry's 1997 petition requesting the ITS allocation. Until the late 1990s, the FCC historically allocated frequency bands to specific, often narrowly defined services with restrictive service rules. This "command-and-control" approach became increasingly subject to criticism by advocates of both flexible licensing and unlicensed use. Narrow, highly-specified allocations can rapidly become obsolete or spectrally inefficient, since "[a]ny narrow allocation locks in a particular technology or spectrum use" long after "it has been surpassed by an existing service or technology ... or by an entirely new service or technology."[148]

For more than half a century the FCC designed exclusive allocations to accommodate specific technologies and business models. The result was a Table of Frequency Allocations derided as "a fossilized record of fading services and technologies."[149] Beginning with the service rules for the new Personal Communications Service (PCS) spectrum allocated for mobile telephones in 1993,[150] the Commission began to allow licensees greater flexibility with respect to both services offered and technologies used.

Just weeks after the Commission adopted its 1999 Report and Order allocating 75 megahertz exclusively for Intelligent Transportation Systems, the agency released a policy statement affirming that "[f]lexible allocations may result in more efficient spectrum markets," while noting that exceptions could be made for public safety and certain other services "where market forces would fail to provide for the operation of important services."[151] Three years later, the FCC's

Spectrum Policy Task Force (SPTF) Report went further, recommending that the Commission "eschew command-and-control regulation" of spectrum use and transition "legacy command-and-control bands to more flexible rules."[152]

Like the Commission's 1999 Spectrum Allocation Principles, the Task Force noted that the agency should continue to make exceptions only in cases "where prescribing spectrum use by regulation is necessary to accomplish compelling public interest objectives," or to conform to treaty obligations.[153] The Task Force Report emphasized that exceptions made for public safety or other public interest allocations should be narrowly defined "*and the amount of spectrum . . . limited to that which ensures that those [compelling public interest] objectives are achieved.*"[154] The Task Force Report went on to warn that since many spectrum users will claim their planned use deserves an "exemption from any reform of their service allocation rules," it is "critical to distinguish between special interests and the public interest, establishing a high bar for any service to clear prior to receiving an exemption."[155]

With respect to allocations not strictly necessary for compelling non-market purposes, such as safety-of-life, the Task Force recommended that "existing spectrum that is subject to command-and-control regulation should be transitioned to the more flexible exclusive use and commons models to the greatest extent possible."[156] The Report further recommended that the "Commission should, where feasible, seek to designate additional bands for unlicensed spectrum use to better optimize spectrum access and provide room for expansion in the fast-growing market for unlicensed devices and networks."[157]

Eight years later, in its 2010 National Broadband Plan, the Commission again distanced itself from its traditional approach to allocating spectrum "on a band-by-band, service-by-service basis, typically in response to specific requests for service allocations or station assignments."[158] The National Broadband Plan states that this approach "has been criticized for being ad hoc, overly prescriptive and unresponsive to changing market needs."[159] Echoing the FCC's 1999 spectrum allocation principles, the Plan asserts that "where there is no overriding public interest in maintaining a specific use, flexibility should be the norm." The Plan goes on to assert that "flexibility in access to spectrum can be just as important" as flexibility in spectrum use, and should increasingly include "unlicensed uses, shared uses and opportunistic uses."[160] The Plan further concludes that "the failure to revisit historical allocations can leave spectrum handcuffed to particular use cases and outmoded services, and less valuable and less transferable to innovators who seek to use it for new services."[161]

> **As the evolution of DSRC demonstrates, given the rapid evolution of wireless technology and mobile apps, the Commission cannot reliably predict what services will be available or which frequency range will be efficient for proposed services a decade or more into the future, much less what the public demand for each service will be and how to respond to changing demand.**

In an early, influential critique of command-and-control allocations, former FCC Chief Economist Greg Rosston warned the Commission "should also be wary of unnecessarily reserving spectrum for future use."[162] As the evolution of DSRC demonstrates, given the rapid evolution of wireless technology and mobile apps, the Commission cannot reliably predict what services will be available or which frequency range will be efficient for proposed services a decade or more into the future, much less what the public demand for each service will be and how to respond to changing demand. For example, in its original 1999 Order allocating the requested 75 megahertz to ITS, the Commission describes a future of autonomous vehicles that, like trains on a track, "would transfer full control of equipped vehicles to an automated system operating on designated AHS [Automated Highway System] lanes."[163] This suggests that even if the Commission could correctly identify the most productive use of spectrum at any given time, it would be obliged continually to modify single-purpose allocations to reflect technological and economic developments.[164]

The FCC's current proposal to open the 5.9 GHz band for sharing on an unlicensed basis is also reinforced by the recommendations of the President's Council of Advisors on Science and Technology (PCAST). In its 2012 report, the PCAST focused on the spectrum efficiency and feasibility of sharing underutilized bands where the military, the FAA, DOT and other agencies needed to continue operating, but where they could do so in a manner that facilitates – rather than prohibits – access and dynamic sharing by other private sector users on a licensed or unlicensed basis, or both. "The essential element of [the] new Federal spectrum architecture is that the norm for spectrum use should be sharing, not exclusivity," the PCAST recommended.[165] It outlined a multi-tiered sharing approach, governed by an automated geolocation database, which the FCC quickly adapted to open the naval radar band at 3.5 GHz for a hybrid licensed and (effectively) unlicensed Citizens Broadband Radio Service.[166] The NTIA has openly embraced this new band-sharing paradigm, stating early in 2015: "The future lies in sharing spectrum – across government agencies and commercial services, and across time, geography and other dimensions in the future."[167]

General Purpose vs. Special Purpose Allocations

The fact that most of the non-safety-of-life applications proposed for DSRC have become available using more general-purpose technologies and networks – most commonly smartphone apps using LTE and Wi-Fi connectivity – is a familiar outcome for narrow, special-purpose allocations. The need to reallocate or reorganize valuable spectrum occupied by special-purpose services that have become outdated or replaced by general-purpose networks is an ongoing challenge for the FCC. An example includes large allocations for "wireless cable" (the Instructional Television Fixed Service and the Multichannel Multipoint Distribution Service) in the 2.5 GHz band, which has been functionally replaced by high-capacity wireline connections and by the cellular/LTE networks that now lease most of the reorganized band.

Another example is the 500 megahertz of contiguous and very valuable spectrum in the C-Band (3700-4200 MHz) allocated primarily for mobile satellite distribution of TV signals to a scattering of fixed earth station receive sites licensed by cable TV networks and others. As the most recent report of the annual

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Aspen Institute Roundtable on Spectrum Policy (AIRS) observed, "[a]lthough this content is now distributed largely through fiber optic networks and the Internet . . . the FCC still protects the [exclusive] allocations."[168] The Aspen Roundtable agreed more generally that the FCC's practice of single-use allocations leading to underutilized spectrum "is flawed from a societal perspective because it creates a classic externality by ignoring the value of alternative uses of the spectrum."[169]

The Commission has repeatedly recognized both the reality and benefits of the migration from special-purpose to general-purpose networks and allocations. For example, in its 2014 NPRM on wireless microphones, the Commission observed that "the past several decades have seen widespread development and deployment of 'general purpose' wireless technology standards that may be used for a wide variety of end-user applications," including the IEEE 802.11 family of standards, and asks whether these technologies could allow wireless mics to operate on a shared basis in one or more of the unlicensed bands.[170]

The Commission's longtime effort to move away from silos of special-purpose use and toward more intensively-used and flexible general-purpose use makes the distinction between DSRC's anticipated real-time safety and non-safety applications critical. As the previous section explained, real-time V2V and V2I communication for crash avoidance will necessarily occupy a single designated safety channel of 10 megahertz. In both the U.S. and Europe, safety-of-life applications are not anticipated to need more than three DSRC channels (30 megahertz in total). The remainder of the 75 MHz allocation for DSRC has always been anticipated to provide multiple channels for a wide variety of non-safety-of-life applications and commercial services, most of which are either already or could be provided most efficiently over existing general purpose LTE and Wi-Fi networks.

A study of wireless market adoption by Harvard Law School Professor Yochai Benkler concludes that the market is rapidly gravitating toward open and general-purpose spectrum bands. Benkler emphasizes that although a particular application's need for real-time connectivity could be an exception to this trend, in general market forces and the need for spectrum efficiency is pushing toward open wireless technologies (such as Wi-Fi) and shared bands:

> The past decade has seen a gradual emergence of what was, fifteen years ago, literally unbelievable: spectrum commons are becoming the basic model for wireless communications, while various exclusive models – both property-like and command-and-control – are becoming a valuable complement for special cases that require high mobility and accept little latency.[171]

In fact, Benkler's survey and analysis of seven wireless product markets (including smart grid communications, health care monitoring, RFID and mobile payments) suggest that consumers – and quite possibly the auto industry itself – would benefit from shared and unlicensed use of at least the lower portion of the 5.9 GHz band. The ability to use Wi-Fi and other open, unlicensed technologies in car systems – either separately or in tandem with DSRC – could stoke innovation and give both consumers and automakers more choices.

For example, Benkler shows that compared to Europe, the U.S. has achieved a far larger and faster deployment of wireless smart grid communications systems (particularly advanced metering infrastructure) because utilities here can directly and freely access the unlicensed 900 MHz ISM band on an unlicensed basis, whereas European utilities need to strike deals with licensed cellular carriers.[172] Benkler also describes how – despite special-purpose spectrum allocations to hospitals for certain critical and real-time patient monitoring (Wireless Medical Telemetry Service devices) – at home and in hospitals personal wearable devices used for medical monitoring primarily use Wi-Fi (and open, shared spectrum) to connect to the Internet.[173] Overall, three unlicensed technologies – Wi-Fi, Bluetooth and Zigbee – had 70 percent of the market share for wireless health care applications as of 2010, a share that's undoubtedly larger now as Wi-Fi has grown far more ubiquitous and reliable.[174]

One irony of the auto industry's determination to retain exclusive or at least priority use of the entire 5.9 GHz band is that at the time ITS America petitioned for a 75 megahertz special-purpose allocation for DSRC in 1997, existing and successful DSRC applications – automatic toll collection (e.g., E-ZPass) – operated on the general-purpose unlicensed band at 900 MHz In its 1998 NPRM, the Commission opined that the 900 MHz LMS band already in use for DSRC applications was a "limited amount of spectrum" and that its increased use by other services "render it inadequate to support the full panoply of DSRC applications."[175] Yet tolling at 900 MHz reliably continues today on a far larger scale. ITS America argued then, as now, that its 75 megahertz cost-free allocation was needed to implement the industry's vision of 11 or more categories of "user services" (such as navigation assistance, driver notifications, traffic monitoring) that would require additional channels. As described in the section above, few if any of these involved real-time safety and most require an extensive roadside

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infrastructure build-out that never happened. The FCC relied on auto industry claims that this "wide array of DSRC applications" would "need [capacity for] up to 32 different DSRC transactions, many of which will require two-way capabilities, wideband channels, and the need for multiple channels in a single location."[176]

Of course, as described in the section above, the reality of that "wide array" of services for consumers proved to be wrong, as it typically is when it comes to claims of amazing public interest benefits from a special-purpose spectrum giveaway. Every one of the 11 categories of DSRC "user services" (applications) cited by the FCC as the rationale for a special-purpose allocation – current, emerging and future applications – today either have proven general-purpose substitutes or depend on the widespread deployment of dense roadside infrastructure by localities nationwide that is widely acknowledged to be unlikely in the foreseeable future (and less so as private spending on driver-assist technology and, ultimately, autonomous vehicles supplant the need for massive public spending). Indeed, even at the time, BellSouth's comments supported a dedicated allocation for DSRC safety-of-life applications, but argued that could be accommodated in far less than 75 megahertz.[177] The Amateur Radio Relay League (ARRL) similarly argued there was no basis for such a large allocation, noting that Europe was considering an allocation limited to 20 megahertz.[178]

SAFETY AND SHARING: OPTIONS FOR SHARED ACCESS TO 5.9 GHZ BAND

In its April 2013 NPRM, the FCC proposed authorizing low-power operation of U-NII (unlicensed) devices across the entire band, from 5850 to 5925 GHz, stating that adding shared, unlicensed use has "great potential for fostering ongoing technological innovation, expanding broadband access, and encouraging competitive entry."[179] Under the Commission's proposal, ITS licensees would retain their primary status, with unlicensed use a secondary allocation obligated to avoid harmful interference to ITS operations. Although the NPRM does not discuss specific sharing scenarios, it does ask "what types of sharing technology or techniques could be used to protect non-radar systems," including specifically V2V and V2I safety applications of DSRC.[180]

As previously discussed in this paper, shortly after the FCC adopted its NPRM, the IEEE formed an inter-industry committee to study the feasibility of alternative approaches to accommodate very low-power unlicensed use while protecting critical DSRC operations from harmful interference. Known as the IEEE 802.11 DSRC Tiger Team, the committee's evaluation and debate focused primarily on two spectrum-sharing proposals, one championed by Cisco (now generally supported by the auto industry) and the other by Qualcomm (now generally supported by leading Wi-Fi users, particularly the cable industry). As noted earlier, the Tiger Team concluded its work without reaching a consensus, dividing along industry lines over variations of the Cisco and Qualcomm approaches to sharing the band.[181] Neither approach was recommended or rejected. The following two sections summarize these two competing approaches and the substantial trade-offs that each entails.

The Cisco Proposal: Sense and Avoid

Cisco proposes to allow shared but conditional unlicensed use of the entire 75 megahertz of the 5.9 GHz band. This scenario is the one assumed by the DOT's DSRC-Unlicensed Device Test Plan, which aims to determine whether or not both uses can co-exist in the same band without significant interference.[182] Unlicensed devices would need to "detect and avoid" DSRC transmissions across the entire band. Under Cisco's proposal, if an unlicensed device operating anywhere in the band detects a DSRC transmission (e.g., a passing vehicle or fixed roadside infrastructure), the device would be required to vacate the entire band for at least 10 seconds. The band is currently divided into seven channels, each

10 megahertz wide. Under Cisco's proposal, if a DSRC transmission is detected on any one of those seven channels – regardless of spectral proximity or whether the transmission relates to a V2V safety or a non-safety commercial application – this forecloses access for unlicensed devices to the entire 75-megahertz band.[183]

In fact, as described in the Tiger Team's report, the Cisco proposal would be even more protective since it would require that if a DSRC signal is detected on any channel, the 100 megahertz from 5825 to 5925 MHz (which includes the 25 megahertz below the ITS band) "will be declared busy for at least 10 seconds."[184] There is no channel move time, as there is for Dynamic Frequency Selection to protect military radar lower in the 5 GHz band. This means that when DSRC is detected anywhere in the band, unlicensed transmissions must instantly cease across the entire 100 megahertz. The 10-second hold period is also "a relatively long period" compared to normal [802.11] deference."[185] In May Cisco, in coordination with the auto industry, announced that it would begin both laboratory and field testing of its proposed approach to sharing the 5.9 GHz band.[186]

The fundamental problem with the Cisco approach, as currently described, is that it would not permit the economically feasible deployment of unlicensed technologies, particularly Wi-Fi. Vacating the entire band if any DSRC transmission is detected on any channel across a 100 megahertz range is an extreme restriction that may effectively exclude Wi-Fi from the band. Motorized vehicles and roads are ubiquitous. If V2V is widely deployed, 802.11ac Wi-Fi and other unlicensed technologies – no matter how low their transmit power – could only operate indoors and away from windows, in places where the constant patter of mandated V2V safety signaling is not detectable. Although the expected NHTSA mandate would apply only to the single DSRC channel designated for real-time V2V signaling, under Cisco's approach the detection of the V2V Basic Safety Message on this 10 megahertz BSM channel precludes, for all practical purposes, the use of 100 megahertz of spectrum capacity for the vast majority of Americans. This would cripple the utility of Wi-Fi for individual consumers as well as for wireless ISPs, small retailers, schools, local governments and virtually all other Wi-Fi users.

An effective indoor-only restriction would be particularly crippling, since consumers increasingly rely on mobile devices and seamless connectivity as they move between locations. Such an extreme detect-and-avoid requirement seems likely to deter widespread use of the additional 80 and 160 MHz 802.11ac channels that would otherwise be available. The cable industry, which has deployed over 400,000 Wi-Fi hotspots in heavily-trafficked outdoor areas, has stated it is not aware of any outdoor Wi-Fi hotspot deployments in the U.S. that use the portions of the 5 GHz band subject to the DFS requirement that requires unlicensed WLAN deployments to detect and avoid military radar.[187] The Cisco proposal for sharing 5.9 GHz would seem to create even stricter and more costly limitations and uncertainties about availability.

The Tiger Team further observed that although Cisco's approach leverages the commonality of 802.11ac (Wi-Fi) and 802.11p (DSRC), "[f]rom a practical perspective, non-802.11 unlicensed devices may not find adding this CCA [detection] method cost effective."[188] Moreover, even the 802.11ac standard already in use across the rest of the 5 GHz band may not be able to sense traffic separately on seven different 10 megahertz DSRC channels, since Wi-Fi is designed to sense on the single channel on which it is operating, in increments of 20 megahertz.[189] Therefore, the Cisco proposal "would require changes in the base 802.11 specification and add complexity to existing 802.11ac chipsets."[190]

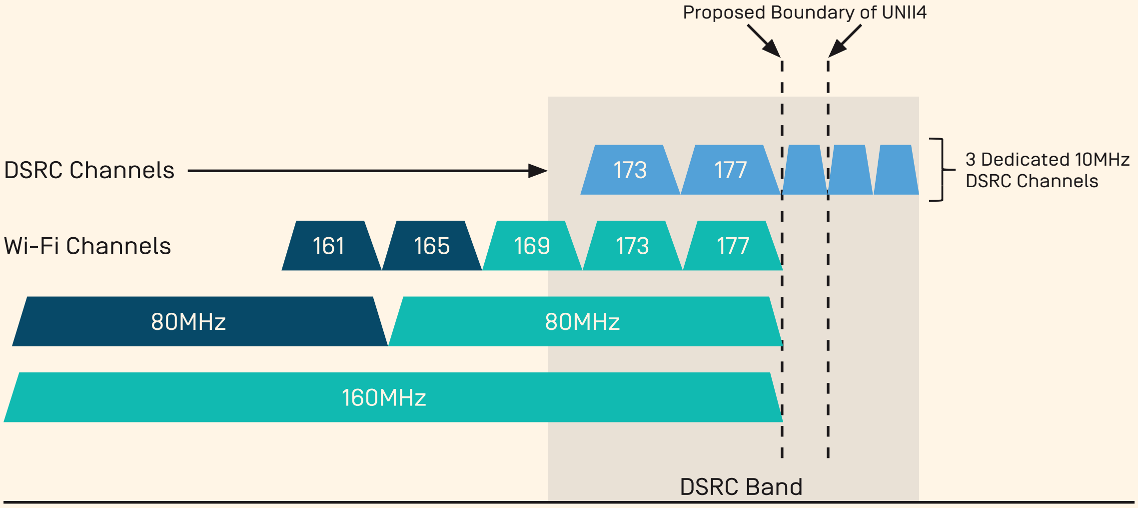
In short, the Cisco proposal would effectively fragment the U-NII band, require a complete retooling of existing 802.11ac devices, and increase device costs – all of which undermine the FCC's goal in proposing the 5.9 GHz band as an extension of the U-NII bands for wide-channel use by 802.11ac Wi-Fi. In contrast, the FCC's proposal to allow unlicensed operations above 5850 MHz under rules that already apply to the neighboring U-NII-3 band would unleash 200 MHz of contiguous and uniquely useful spectrum that accommodates the only unfettered 160 megahertz channel sufficient to support truly gigabit Wi-Fi networks. The Cisco approach would provide a feasible path forward only if it adopted a more reasonable detection threshold and required unlicensed devices to vacate only the specific channels where DSRC activity is detected. But without such a proposal on the table, it is difficult to analyze it further.

The Qualcomm Proposal: Segment the Band and Share Only Non-Safety Channels

The leading alternative to the Cisco approach, proposed by Qualcomm, would reorganize the 5.9 GHz band to give V2V and V2I real-time safety applications exclusive use of three channels, while sharing the remainder of the band (45 megahertz) between unlicensed and non-safety DSRC applications.[191] Qualcomm's proposal would move safety-of-life DSRC applications to the three 10 MHz channels at the top of the band. Unlicensed devices would not be authorized to transmit on these safety channels. Under the Qualcomm proposal, non-safety-of-life DSRC applications would operate on 20 MHz channels in the lower 45 MHz of the band (5850-5895 MHz), rather than the current 10 MHz channel size. Unlicensed devices would share access to this 45 MHz on a secondary and non-interfering basis, using a more conventional 802.11 listen-before-talk protocol that gives priority to DSRC operations.[192]

Figure 5

Proposal to Reband DSRC with Three Exclusive Safety/DSRC Channels at Top



Source: Landsford, et al., "Final Report of DSRC Coexistence Tiger Team," IEEE (Mar. 9, 2015), at p. 7, available at https://mentor.ieee.org/802.11/dcn/15/11-15-0347-00-0reg-final-report-of-dsrc-coexistence-tiger-team-clean.pdf.

Unlike the FCC's proposal, Qualcomm's approach is premised on segmenting the band based on the critical distinction between V2V and V2I safety-of-life applications – which would operate on designated channels not shared with Wi-Fi – and other DSRC channels used for non-safety-of-life applications, most of which compete with similar applications delivered over other wireless networks and can also generally tolerate packet delay. Qualcomm acknowledges in its FCC comments that if unlicensed devices could operate across the entire 5.9 GHz band, as the FCC proposed in its NPRM, it could be "virtually impossible to completely eliminate interference from the wide deployment and use of Wi-Fi devices," especially since "Wi-Fi usage within vehicles via mobile hotspots and vehicle cellular connectivity is growing every day."[193] But while a NHTSA mandate would require vehicles to constantly transmit a Basic Safety Message on a single channel dedicated for V2V safety-of-life, the non-safety channels would only be occupied when and where needed, presumably leaving unused capacity available for unlicensed use.

Qualcomm proposes that both services operate on 20 MHz channels in the shared, non-safety portion of the 5.9 GHz band, since DSRC's 10 MHz transmissions "would not be detectable by existing Wi-Fi devices."[194] As Qualcomm puts it, since both DSRC and Wi-Fi are 802.11 standards, they "'speak' the same 20 MHz 'language.'"[195] Leveraging their common 802.11 underpinnings would allow, according to Qualcomm, "packet-by-packet channel sharing and maximize the spectrum usage for both DSRC and Wi-Fi devices."[196] The Tiger Team's Final Report states that if both of these 802.11 services operated on 20 MHz channels, "modification of the existing 802.11ac standard to incorporate 20 MHz Carrier Sense [CCA sensing] in the U-NII-4 band would likely not result in a major change (if any) to existing standards or chipsets, since 20 MHz CCA is already defined and in use."

In other words, unlike the Cisco approach, under Qualcomm's proposal Wi-Fi 802.11ac devices could detect-and-avoid non-safety DSRC transmissions on the channel they are sharing, but without the need to retool the existing 802.11ac standard or limit unlicensed use to a new class of indoor-only devices capable of a detect-and-vacate-the-band restriction. More importantly for consumer broadband access and spectrum efficiency, the Qualcomm proposal could accommodate the FCC's proposal to permit indoor and outdoor deployments under technical rules compatible with the adjacent U-NII-3 unlicensed band – thereby realizing the broader public interest benefits of 80 and 160 MHz channel widths ("gigabit Wi-Fi") that would be effectively foreclosed under the Cisco approach.

The downside of the Qualcomm proposal is that although neither safety-related nor non-safety-related DSRC applications have been deployed, moving the Basic Safety Message from DSRC channel 172 (at the bottom of the ITS band) to the top of the band may require some additional re-testing. The Tiger Team report acknowledges that substantial aspects of the existing tests would still be relevant (since the channels would still be 10 MHz and move only slightly in terms of propagation), nevertheless "the potential for new forms of co-channel interference, adjacent channel interference, and congestion would mean that some portions of the testing would have to be re-done." However, Qualcomm has asserted that if the safety channel is exclusive to BSM, as NHTSA has proposed, neither co-channel interference nor the amount of traffic on the dedicated safety channels should change simply because they move up the frequency band. And since NHTSA has not yet adopted a mandate for V2V – and has said that the industry will be given a multi-year transition period – an expedited decision on the future of sharing the band will not necessarily cause undue delay even if it involves some additional testing.

The DOT added its own perspective on the two proposals as an appendix to the Tiger Team report. Although the agency states that "insufficient detail was provided to reach any conclusions on either approach's risk to transportation safety use," it questions the workability of Qualcomm's band segmentation proposal. First, DOT states that 30 megahertz "is insufficient to support even a portion of all planned safety applications" for V2V and V2I – although, considering that NHTSA has concluded it will require V2V safety messaging on a single BSM channel, it is unclear what other real-time safety applications would require more than an additional dedicated 20 megahertz. Second, DOT notes its concern that moving the basic safety, control and higher-power public safety channels "would be expected to substantially increase adjacent channel interference levels," placing the effectiveness of imminent crash notification alerts at risk. Finally, DOT claims a reorganization of the band "would require much of this [safety] research and testing work to be repeated," entailing delay and substantial added costs.[197]

CONCLUSION AND POLICY RECOMMENDATIONS

Both DSRC safety-of-life applications and expanded broadband capacity for Wi-Fi would deliver important benefits for virtually all Americans. As the FCC tentatively concluded in its 2013 NPRM, the public interest would best be served if the two services can coexist and share at least a portion of the 5.9 GHz band without causing harmful interference to DSRC operations – particularly V2V crash avoidance and other safety-of-life communications.

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As noted above, after 18 months of presentations and deliberations on the competing Cisco and Qualcomm approaches, the IEEE "Tiger Team" could not reach consensus and released a final report that neither endorsed nor rejected either approach. The final report states that "more work needs to be done beyond the time frame of this tiger team before any definitive technical recommendations could be made."[198]

Faced with this deadlock, in September 2015 a trio of U.S. senators encouraged the opposing industry groups and the three federal agencies (FCC, DOT and Commerce) to collaborate on the testing needed to evaluate the feasibility and trade-offs of alternative approaches to sharing the 5.9 GHz band. Three members of the Senate Commerce Committee (Chairman John Thune, along with Senators Cory Booker and Marco Rubio), which oversees both industries, in parallel with a group of six leading industry players from the opposing camps, including the auto and cable industries, sent nearly identical letters urging the FCC to take the lead in facilitating interference and coexistence testing of the competing proposals no later than the end of 2016.[199] The letters set forth nine goals and principles that should govern the testing, including industry participation, transparency to the public, and cooperation from all parties (e.g., making devices and data available).

We recommend that the FCC develop and release a Public Notice during the first quarter of 2016 proposing a process and timeline for the requisite testing. Assuming that both the Cisco and Qualcomm proposals are technically feasible, it seems likely the FCC will conclude that the Qualcomm approach (or a variation of it) strikes a better balance between DOT's interest in promoting auto safety and the Commission's interest in promoting ubiquitous broadband connectivity and innovation. The critical factor in striking this balance is the distinction between real-time safety and non-safety DSRC applications described in Section 3 above. By dedicating three channels exclusively to DSRC safety – including the single Basic Safety Message channel that NHTSA describes as essential to real-time V2V crash avoidance alerts – the Qualcomm proposal greatly reduces the risk of unlicensed device interference with safety-of-life applications, while at the same time adhering to the evolving principles of spectrum efficiency and flexibility that the FCC increasingly applies to non-safety wireless services, particularly to those that are largely redundant and even subject to robust competition (such as DSRC navigation assistance, weather alerts, toll collections, etc.).

Additional considerations also lead us to conclude that segmenting the band, if feasible, strikes a better balance overall:

First, if NHTSA adopts its proposed V2V mandate, the Cisco detect-and-vacate-the-band approach, as currently envisioned, would effectively and needlessly preclude 802.11ac Wi-Fi, or future variations of unlicensed broadband or device-to-device access, to 100 MHz of spectrum (the entire 5.9 GHz band and the adjacent 5825-5850 MHz). Since a V2V mandate would require that vehicles use the BSM safety channel to constantly communicate their location, heading, speed and other data to surrounding vehicles, the continual and ubiquitous traffic on this single 10 MHz channel could exclude unlicensed devices from the entire 5.9 GHz band, with the exception of those inside well-shielded buildings and away from streets and vehicles – unless the Cisco proposal's detection threshold and channel vacation elements become more reasonable. This would restrict the benefits of extended gigabit Wi-Fi connectivity to indoor enterprise Wi-Fi systems (such as hotels, convention center, corporate campuses), while denying those benefits to individual households and other business establishments located close to streets and vehicles.

Second, even if the strict detect-and-avoid approach proposed by Cisco is appropriate to protect the DSRC channels necessary to implement a NHTSA auto safety mandate, a requirement to make all DSRC channels unavailable for unlicensed transmissions seems both unnecessary and likely to result in a continued waste of the band's carrying capacity. It's not clear that non-safety DSRC applications will ever be widely deployed, in demand by consumers, or even needed by the time they are feasible. Non-safety applications will necessarily need to wait for widespread deployment of V2V safety systems, which NHTSA itself estimates will take 15 to 30 years or longer (see Section 3 above). Since applications available via smartphones and car-based connectivity by general-purpose cellular and Wi-Fi networks already offer most of the functionality promised by DSRC, the auto industry will need to innovate ahead of the tech and telecom companies to differentiate their future offerings. Competing DSRC applications will appear even more obsolete when they are widely available in a decade or so, when clouds of 5G connectivity can serve the same purpose without the extra cost.

Third, the bandwidth needs of vehicle-to-infrastructure (V2I) are both speculative and likely to be modest. As explained in Section 3 above, NHTSA will not mandate deployments of fixed roadside units, nor is the federal government contemplating a multi-billion dollar expenditure to integrate V2I even as part of the federal highway system, which represents a tiny share of America's road miles. Nor is it likely that the thousands of state, county and municipal jurisdictions, most already fiscally squeezed, will decide that this investment is a priority. And although there will certainly be many cities and counties that deploy elements of V2I in the future (e.g., traffic signals that adapt to changing traffic congestion), the applications cited by DSRC proponents are, like V2V itself, almost entirely narrowband and short duration, using relatively little overall bandwidth. More critically, these V2I applications can tolerate more latency than V2V Basic Safety Messages and, to the extent they cannot, can be accommodated on the three exclusive DSRC safety channels. V2I deployments would also likely be limited to highways and major thoroughfares, whereas the benefits of 802.11ac could be available immediately and up and down every street under an approach more similar to Qualcomm's.

Finally, as explained in Section 4 above, maintaining an exclusive and underutilized spectrum allocation for non-safety-of-life DSRC applications runs counter to the FCC's commitment to the more flexible and efficient spectrum management principles the agency first embraced 15 years ago. The Commission must continue its effort to move away from silos of special-purpose spectrum bands and toward more intensively-used and flexible general-purpose use of spectrum. As both the FCC's 2002 Spectrum Policy Task Force and the FCC's 2010 National Broadband Plan emphasized, exceptions made for public safety

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or other public interest allocations should be narrowly defined "and the amount of spectrum . . . limited to that which ensures that those [compelling public interest] objectives are achieved."[200] The effectively exclusive allocation and non-use of most of the

75 megahertz allocated for DSRC contradicts the Obama Administration's historic initiative to open underutilized federal bands for sharing to the greatest extent feasible. As the PCAST recommended and NTIA and the Department of Defense and other federal agencies have increasingly agreed: "The essential element of [the] new Federal spectrum architecture is that the norm for spectrum use should be sharing, not exclusivity."

In sum, the FCC and the Obama Administration should expedite a collaborative testing process aimed at a win-win compromise that permits the two services – DSRC and U-NII devices – to coexist and share at least a portion of the 5.9 GHz band without causing harmful interference to V2V crash avoidance and real-time safety-of-life communications. If collaborative testing shows that unlicensed devices are incompatible with safety-of-life applications using DSRC, such as the narrowband vehicle-to-vehicle (V2V) signaling that NHTSA is on a path to mandating this year, a decision must be made as soon as possible to move the safety channels to the top of the band – furthest away from Wi-Fi operations. This can be done without undue delay since there are no commercial deployments of either DSRC for safety or 802.11ac for Wi-Fi anywhere on the band across the U.S. and NHTSA is expected to give automakers a multi-year transition period before requiring DSRC in every new car sold.

ENDNOTES

1 FCC Chairman Julius Genachowski first warned of a "looming spectrum crisis" in an Oct. 6, 2009 speech to CTIA, the wireless industry trade association. See FCC Chairman Julius Genachowski, Prepared Remarks at the CTIA Wireless IT & Entertainment Show 2009 (Oct. 7, 2009), available at https://apps.fcc.gov/edocs_public/attachmatch/DOC-293891A1.pdf. See also FCC Chairman Julius Genachowski, Remarks at the 2012 Consumer Electronics Show (Jan. 11, 2012) ("America's global leadership in mobile . . . is being threatened by the looming spectrum crunch."), available at http://www.fcc.gov/document/chairman-genachowski-2012-consumer-electronics-show.

2 One of the many proven benefits of Wi-Fi is that it facilitates spectrum frequency re-use over very small areas (a home, business, or school). As Sprint has explained, Wi-Fi "gains its efficiency and speeds in part because it only needs to use radio transmission for a very small portion of the end-to-end route taken by data traffic. The vast majority of the route is along the less traffic-sensitive wired network." See Comments of Sprint Nextel Corporation, WT Docket No. 12-4 (Feb. 21, 2012), at p. 5. (emphasis added).

3 See Mary Meeker, Internet Trends 2015–Code Conference, Kleiner Perkins Caufield Beyers (May 27, 2015), at p. 14, available at http://kpcbweb2.s3.amazonaws.com/files/90/Internet_Trends_2015.pdf?1432854058.

4 See Commissioner Jessica Rosenworcel, Remarks at SXSW Interactive, Austin, Texas (Mar. 16, 2015), available at https://www.fcc.gov/document/remarks-commissioner-jessica-rosenworcel-sxsw-interactive.

5 See Monica Alleven, "Wheeler Gives Shout-Out to Unlicensed Spectrum Sharing," FierceWirelessTech (Jun. 26, 2015), available at http://www.fiercewireless.com/tech/story/wheeler-gives-shout-out-unlicensed-spectrum-sharing/2015-06-26.

6 Michael O'Rielly and Jessica Rosenworcel, "Driving Wi-Fi Ahead: the Upper 5 GHz Band," FCC Blog (Feb. 23, 2015), available at https://www.fcc.gov/news-events/blog/2015/02/23/driving-wi-fi-ahead-upper-5-ghz-band.

7 See Raul Katz, Assessment of the Economic Value of Unlicensed Spectrum in the United States, Telecom Advisory Services (Feb. 2015), at p. 14, available at: http://www.wififorward.org/wp-content/uploads/2014/01/Value-of-Unlicensed-Spectrum-to-the-US-Economy-Full-Report.pdf.

8 Robert Pepper, Cisco Visual Networking Index (VNI) Mobile Data Traffic Update, 2014-2019, presentation at Mobile World Congress, GSMA Seminar (Mar. 3, 2015), available at http://www.gsma.com/spectrum/wp-content/uploads/2015/03/MWC15-Spectrum-Seminar.-Dr-Roberto-Pepper.-Cisco-presentation.pdf. Globally Cisco projects that by 2018 more than 60 percent of all Internet traffic (fixed and mobile) will connect to the end user over a Wi-Fi connection, including both mobile device offload and home/enterprise routers.

9 See Mobidia, "Network Usage Insights: Average Data Usage for LTE, 3G and Wi-Fi of Wireless Subscribers in the USA, Q3 2014" (Nov. 2014).

10 See J. Scott Marcus and John Burns, Study on the Impact of Traffic Off-Loading and Related Technological Trends on the Demand for Wireless Broadband Spectrum, European Commission, at p. 3 (Aug. 2013). The E.C. study used data from surveys that monitored the actual activity of thousands of mobile devices to project offload rates for the U.K., France, Spain, Germany and Italy.

11 According to the 2012 Cisco survey, users report that two-thirds of their mobile device use for broadband applications is at home or work, while only 10-to-15 percent is "on the go" or outside of retail and public locations that are increasingly wired for Wi-Fi access. See Stuart Taylor, Andy Young and Andy Noronha, What do Consumers Want from Wi-Fi? Insights from Cisco IBSG Consumer Research (May 2012), at 5; See also Stuart Taylor, What do Mobile Business Users Want from Wi-Fi? Insights from Cisco IBSG Consumer Research (Nov. 2012), at p. 6. Similarly, the 2013 Cisco user survey report states: "The 'nomadic' use of mobile devices continues to evolve, as many people now use their mobile devices in 'mobile stationary' locations" that are increasingly served by fixed Wi-Fi access. Taylor and Christensen, Understanding the Changing Mobile User, supra, at p. 4.

12 Pepper, supra note 8, at p. 36. Cisco's most recent VNI projects video will surpass 80% globally, up from 67% in 2014. See Cisco Visual Networking Index (VNI): Forecast and Methodology, 2014-2019, Cisco, (May 27, 2015) ("Cisco Visual Networking Index"), available at http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html. Verizon reported that online video exceeded 50% of its mobile data traffic in 2013, a share the company projected will increase to two-thirds of all mobile broadband traffic by 2016. See Sue Marek, "Verizon CEO: 50% of Our Wireless Traffic is Video," Fierce Wireless (April 10, 2013), available at http://www.fiercewireless.com/story/verizon-ceo-50-our-wireless-traffic-video/2013-04-10?utm_source=rss&utm_medium=rss; see also "Executive Summary," Cisco Visual Networking Index Global Mobile Data Traffic Forecast Update, 2011–2016, Cisco (Feb. 3, 2015), available at http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html.

13 See Stuart Taylor, A New Chapter for Mobile? How Wi-Fi Will Change the Mobile Industry as We Know It, Cisco Internet Business Strategy Group, at p. 6 (Nov. 2011).

14 Kevin Fitchard, "Wi-Fi: A Beautiful Chaos – Part 2," GigaOm (Sep. 9, 2014), available at http://www.wi-fi.org/beacon/kevin-fitchard/wi-fi-a-beautiful-chaos-part-2#sthash.ThWaXOLB.dpuf.

15 See Comments of Wi-Fi Alliance, Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology, ET Docket No. 15-105 (Jun. 11. 2015), at 7 ("Comments of Wi-Fi Alliance").

16 See Wi-Fi Alliance, "Wi-Fi Alliance celebrates 15 years of Wi-Fi," Press Release, (Sep. 8, 2014), available at http://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-celebrates-15-years-of-wi-fi.

17 Mobidia, "Mobidia's Data Shows Private and Self-Provisioned Wi-Fi Traffic Dominate Smartphone Data Consumption," FierceWirelessTech (Feb. 21, 2103), available at http://www.fiercewireless.com/tech/press-releases/research-provides-new-insight-role-managed-public-wi-fi-hotspots-smartphone-0. See also Tammy Parker, "AT&T's numbers show carriers' public Wi-Fi networks may not be justifiable," FierceWirelessTech (Feb. 21, 2103), available at http://www.fiercewireless.com/tech/story/atts-numbers-show-carriers-public-wi-fi-networks-may-not-be-justifiable/2013-02-21.

18 One example is the enormous cost savings experienced by mobile carriers attributable to Wi-Fi connections carrying the majority of their customer's smartphone data traffic. A 2012 study by Consumer Federation of America economist Mark Cooper found that Wi-Fi

offloading, in addition to reducing the spectrum needed by U.S. carriers, also reduced the infrastructure costs of cellular broadband service by roughly $20 billion per year, "which is a substantial savings in a market with annual revenues of $70 billion." See Comments of Consumer Federation of America, In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Docket No. 12-268, FCC 12-118 (rel. Jan. 25, 2013), at pp. 2, 19 (updating key findings from its previously published study on the economics of Wi-Fi offloading).

19 Raul Katz, Assessment of the Future Economic Value of Unlicensed Spectrum in the United States, Telecom Advisory Services (Aug. 2014), at p. 28, available at http://www.wififorward.org/wp-content/uploads/2014/01/Katz-Future-Value-Unlicensed-Spectrum-final-version-1.pdf. Katz's estimate of economic value included both consumer and producer surplus for residential Wi-Fi, Wi-Fi offloading from mobile devices, RFID and Wi-Fi only tablets. Katz also estimated that unlicensed operations contributed $6.7 billion to the nation's GDP in 2013, a contribution that will grow to $13.5 billion by 2017. See also Raul Katz, Assessment of the Economic Value of Unlicensed Spectrum in the United States, Telecom Advisory Services (Feb. 2014), at p. 72.

20 See Comments of Consumer Electronics Association, ET Docket No. 15-105 (Jun. 11, 2015), at p. 3, notes 6 and 7 ("Comments of CEA"); see also Paul Milgrom, Jonathan Levin, and Assaf Eilat, The Case for Unlicensed Spectrum (Oct. 2011), at p. 19 ("Milgrom Study") (estimating the economic value of the share of mobile data traffic carried by Wi-Fi to be at least $25 billion annually), available at http://web.stanford.edu/~jdlevin/Papers/UnlicensedSpectrum.pdf.

21 See Comments of Consumer Electronics Association, Revision of Part 15 in the 5 GHz Band, ET Docket No. 1349 (May 28, 2013), at p. 7.

22 See Paul Milgrom et al., The Case for Unlicensed Spectrum (Oct. 2011), at p. 2

23 Cisco Visual Networking Index (VNI): Forecast and Methodology, 2014-2019, supra note 12.

24 See Yochai Benkler, Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption, 26 HARV. J. L. & TECH. 1 (Fall 2012) ("Benkler Study"), at p. 72.

25 *See id*. at p. 110. ("A single major provider in this market, Sensus, uses its own licensed spectrum. It serves 20% of the market") (citations omitted). Similarly, nearly all of the nation's estimated 2,000 Wireless Internet Service Providers (WISPs) rely entirely or primarily on unlicensed spectrum to provision fixed-wireless broadband in underserved rural, exurban and small town markets.

26 *See id*. at p. 110-113.

27 See Richard Thanki, The Economic Significance of License-Exempt Spectrum to the Future of the Internet (June 2012), at p. 65.

28 See President's Council of Advisors on Science and Technology, Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth, Report to the President (Jul. 2012) ("PCAST Report"), at p. 41; see also Hans Vestberg, President and CEO, Ericsson, Address to Shareholders (Apr. 13, 2010) (predicting 50 billion connected devices by 2020), available at http://www.ericsson.com/thecompany/press/releases/2010/04/1403231.

29 James Manyika, et al., Disruptive Technologies: Advances that Will Transform Life, Business and the Global Economy, McKinsey Global Institute (May 2013), available at http://www.mckinsey.com/insights/business_technology/disruptive_technologies.

30 Chairman of Council of Economic Advisors Jason Furman, "Remarks on Public Sector Spectrum Policy," Brookings Institution (Sep. 23, 2014), available at http://whitehouse.gov/sites/default/files/docs/remarks_on_public_sector_spectrum_policy_jf.pdf.

31 Rob Alderfer, Wi-Fi Spectrum: Exhaust Looms, CableLabs (May 28, 2013), at p. 4.

32 See Comments of Google Inc. and Microsoft Corporation, Revision of Part 15 in the 5 GHz Band, ET Docket No. 1349 (May 28, 2013), at p. 3.

33 Cisco's VNI update reports that average Wi-Fi connection speeds in North America are 17.4 Mbps, the fastest in the world, and are expected to increase to 29 Mbps by 2019 as more and more homes and businesses upgrade to higher-capacity cable and fiber broadband connections. Cisco Visual Networking Index (VNI): Forecast and Methodology, 2014-2019, supra note 12.

34 Federal Communications Commission, In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, ET Docket No. 13-49 (rel. Feb. 20, 2013) ("5 GHz FNPRM"), at ¶ 80.

35 See Cisco, 802.11ac: The Fifth Generation of Wi-Fi, Technical White Paper (Mar. 2014), available at http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-3600-series/white_paper_c11-713103.html.

36 Id. at p. 3. The 802.11ac standard has a link data rate of approximately 1 Gbps, compared to 54 Mbps for the 802.11a standard and 54 to 600 Mbps for the 802.11n standard. 5 GHz NPRM, at ¶ 18.

37 Id. at p. 4; Motorola Solutions, What You Need to Know About 802.11ac (Jul. 2012), at p. 4-5, available at http://goo.gl/kzggg4.

38 Id. at p. 4.

39 Id. at p. 4-5.

40 See 5 GHz FNPRM at ¶ 97. Moreover, as Cisco noted in its Comments supporting the Commission's proposal, "because that spectrum is contiguous to the U-NII-2C and U-NII-3 bands, opening it for [unlicensed use] creates a contiguous block of 455 megahertz that will accommodate substantially more wide channels than are available today – ten 40 MHz channels, five 80 MHz channels, or two 160 MHz channels." See Comments of Cisco, ET Docket No. 13-49 (May 28, 2013), at pp. 57-58.

41 In 1997 the FCC made available 300 megahertz of spectrum at 5.15-5.25 GHz (the U-NII-1 band), 5.25-5.35 GHz (U-NII-2A), and 5.725-5.825 GHz (U-NII-3) for use by a new category of unlicensed equipment, U-NII devices, which are regulated under Part 15, Subpart E of the Commission's rules. In 2003 the agency made an additional 255 megahertz of spectrum available in the 5.47-5.725 GHz (U-NII-2C) for U-NII devices. In the 2013 NPRM that is the subject of this paper, the FCC proposed adding an additional 195 megahertz, the uppermost portion of which (a new U-NII-4 band) to include unlicensed sharing of the 75 megahertz ITS band. See 5 GHz FNPRM at ¶ 4.

42 The Road Ahead: Advanced Vehicle Technology and its Implications, Hearing before Committee on Commerce, Science, and Transportation, U.S. Senate, 113th Cong. (May 15, 2013) (Statement of Senator John Thune), available at https://www.commerce.senate.gov/public/index.cfm/hearings?Id=F228343F-36B3-4517-B01F-9F15624EB05D&Statement_id=843F1040-4110-4E5A-AD60-2B43D3F8BACF.

43 See Comments of Intelligent Transportation Society of America, ET Docket No. 13-49 (May 28, 2013), at p. 36.

44 See Comments of IEEE 802.11, ET Docket No. 13-49 (May 28, 2013), at p. 30.

45 See Comments of Qualcomm Inc., ET Docket No. 13-49 (May 28, 2013), at p. 9.

46 Pub. L. 102-240, at § 6052.

47 U.S. Department of Transportation, "DOT and IIHS Announce Historic Commitment from 10 Automakers to Include Automatic Emergency Braking on All New Vehicles," Press Release (Sep. 11, 2015) ("DOT AEB Press Release"), available at **http://www.transportation.gov/briefing-room/us-dot-and-iihs-announce-historic-commitment-10-automakers-include-automatic-emergency**. The ten companies committing to make automatic emergency braking standard equipment are Audi, BMW, Ford, General Motors, Mazda, Mercedes Benz, Tesla, Toyota, Volkswagen and Volvo.

48 Id.

49 See Bill Vlasic, "Automakers Will Make Automatic Braking Systems Standard in New Cars," The New York Times (Sep. 12, 2015), at p. B1. Rear-end collisions account for one-third of all motor vehicle crashes, injuries and property damage. National Highway Traffic Safety Administration, U.S. Dept. of Transportation, Traffic Safety Facts 2013 (2014), at p. 70, available at **http://www-nrd.nhtsa.dot.gov/Pubs/812139.pdf**.

50 Harding, J. et al., Vehicle-to-vehicle communications: Readiness of V2V technology for application, National Highway Traffic Safety Administration, Report No. DOT HS 812 014 (Aug. 2014) ("V2V Readiness Report"), at p. 27.

51 See Transportation Equity Act for the 21st Century, Pub. L. 105-178, at § 5207 (1998) ("TEA-21").

52 TEA-21 at § 5206(f).

53 See Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services, ET Docket No. 98-95 (Oct. 22, 1999), available at **http://transition.fcc.gov/oet/dockets/et98-95/**.

54 V2V Readiness Report, at p. 24.

55 "NHTSA will use the responses to this ANPRM and the research report . . . to develop a regulatory proposal that would require V2V devices in new vehicles in a future year...." Department of Transportation, National Highway Traffic Safety Administration, 79 Fed. Reg. 49,270 (proposed Aug. 20, 2014) (to be codified at 49 C. F. R. pt. 9701) ("ANPRM"). *Id.* at p. 1.

56 Id. at p. 6.

57 V2V Readiness Report, supra note 50, at p. 68.

58 NHTSA states that it would take 37 years for a mass deployment of DSRC technology to fully penetrate the U.S. automotive fleet. V2V Readiness Report, at p. 24. This is discussed further in Section C below.

59 5 GHz NPRM at p. 2.

60 The IEEE ultimately did not adopt the Tiger Team report and simply pointed the FCC to the full body of the Tiger Team's work, including competing proposals for sharing the band that are discussed in the final section of this paper.

61 Landsford, et al., "Final Report of DSRC Coexistence Tiger Team," IEEE (Mar. 9, 2015), at p. 7, available at **https://mentor.ieee.org/802.11/dcn/15/11-15-0347-00-0reg-final-report-of-dsrc-coexistence-tiger-team-clean.pdf.**

62 Notice of Ex Parte filed by Frederick M. Joyce on behalf of the Alliance of Automobile Manufacturers, the Association of Global Automakers, and Cisco, ET Docket No. 13-49 (May 6, 2015).

63 U.S. Department of Transportation, DSRC-Unlicensed Device Test Plan, Version 3.5.3, at p. 20 (August 2015).

64 Wi-Fi Innovation Act, S.424, 114th Cong. 1st Sess. (Feb. 10, 2015), available at **https://www.congress.gov/114/bills/s424/BILLS-114s424is.pdf**; Wi-Fi Innovation Act, H.R.821, 114th Congr, 1st Sess. (Feb. 10, 2015), available at **https://www.congress.gov/114/bills/hr821/BILLS-114hr821ih.pdf**. The bills would require the FCC to solicit comments on proposals for "interference-mitigation" techniques and technologies (including potential rechannelization) that could permit the band to accommodate both existing users and "widespread commercial unlicensed operations," including outdoor Wi-Fi operations. See Laura Stefani, "Congress Steps Back into Wi-Fi-Related Spectrum Fight," CommLawBlog (Mar. 2, 2015), available at **http://www.commlawblog.com/2015/03/articles/unlicensed-operations-and-emerging-technologies/congress-steps-back-into-wi-fi-related-spectrum-fight/**.

65 See "Commerce Leaders Forge Accord to Test Vehicle-to-Vehicle Spectrum Sharing," U.S. Senate Committee on Commerce, Science, and Transportation, Press Release (Sep.10, 2015), available at **http://www.commerce.senate.gov/public/index.cfm/2015/9/commerce-leaders-forge-accord-to-test-vehicle-to-vehicle-spectrum**.

66 See Mike Lukuc, "Light Vehicle Driver Acceptance Clinics: Preliminary Results," U.S. Department of Transportation (May 21, 2012).

67 See Petition of the Intelligent Transportation Society of America for Amendment of the Commission's Rules To Add Intelligent Transportation Services (ITS) as a New Mobile Service With Co-Primary Status in the 5.850 to 5.925 GHz Band, FCC 98-95 (May 19, 1997) ("ITS Petition to the FCC"), available at **http://apps.fcc.gov/ecfs/comment/view?id=183641**.

68 Federal Communications Commission, Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz band, WT Docket No. 01-90 (rel. July 26, 2006), available at **https://apps.fcc.gov/edocs_public/attachmatch/FCC-06-110A1.pdf**.

69 "The current V2V operation uses two radios, one tuned to channel 172 and dedicated for [basic safety messaging] and another tuned to channel 174 for security-related communications. In addition, a third channel, 178, is used as a control channel to manage channel switching to support messages on other channels related to other services/applications, such as mobility or environment." V2V Readiness Report, at p. 93, 94-96 (explaining why a DSRC system with a single radio "causes a concern for V2V safety").

70 See Comments of National Cable & Telecommunications Association (NCTA), Re: Federal Motor Vehicle Safety Standards: Vehicle-to-Vehicle (V2V) Communications, Docket No. NHTSA-2014-0022 (Oct. 20, 2014) ("Comments of NCTA"), at p. 3.

71 See V2V Readiness Report at p. 41-44. The report suggests that although NHTSA's statutory authority is generally limited to motor vehicles, it "could . . . end up being important for NHTSA to regulate some aspects of infrastructure as a way to avoid regulatory gaps that could critically compromise the overall [DSRC] system." NHTSA concludes that it will need to further evaluate its authority to regulate roadside equipment that interacts with onboard V2V systems in the future.

72 A comprehensive 2014 report by the Association of American State Highway and Transportation Officials (AASHTO) concludes that although a substantial V2I deployment targeted at high-volume intersections and roadways could work in tandem with V2V by 2040, the timing and extent of such infrastructure would depend greatly on the rate of V2V adoption, as well as federal and local funding. DOT and AASHTO, National Connected Vehicle Field Infrastructure Footprint Analysis, Final Report (June 27, 2014), available at **http://stsmo.transportation.org/Documents/AASHTO%20Final%20Report%20_v1.1.pdf**.

73 Only 1 percent of the nation's 4.1 million miles of public roadways are part of the Interstate Highway System. These 47,000 miles of interstate highway represent less than a third of the nation's total highway miles (186,000 in total, as of 2011). See Federal Highway Administration, Office of Highway Policy Information, "Our Nation's Roadways: 2011," available at https://www.fhwa.DOT.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm.

74 DOT AEB Press Release, supra note 47. The ten automakers that agreed in September 2015 to make sensing-based automatic braking systems standard equipment in all new model cars represented 57 percent of total U.S. car and light truck sales in 2014.

75 See Tesla Blog, "Your Autopilot has Arrived" (Oct. 14, 2015), available at https://www.teslamotors.com/blog/your-autopilot-has-arrived.

76 See Chaitra Satish, Inter-Vehicular Communication for Collision Avoidance Using Wi-Fi Direct, Doctoral Thesis, Rochester Institute of Technology (March 2014), available at http://scholarworks.rit.edu/cgi/viewcontent.cgi?article=8669&context=theses. "Wi-Fi Direct technology can be used as an alternate to DSRC to exchange safety messages. Wi-Fi Direct enabled smartphones can exchange important safety information without the need of additional equipment." Id. at 4. See also Priyanka Angadi, Increased Persistence of Wi-Fi Direct Networks for Smartphone-based Collision Avoidance, Doctoral Thesis, Rochester Institute of Technology (July 2014), available at http://scholarworks.rit.edu/cgi/viewcontent.cgi?article=9663&context=theses.

77 NHTSA, ANPRM, "Executive Summary," supra note 55.

78 For a partial list, see Table 2.

79 See Alderfer, et al., Optimizing DSRC Safety Efficacy and Spectrum Utility in the 5.9 GHz Band, Attachment to Comments of NCTA to NHTSA (Oct. 20, 2014) at p. 10, available at http://www.regulations.gov/#!documentDetail;D=NHTSA-2014-0022-0932. "A variety of other services have been envisioned by DSRC stakeholders, though these services are generally ancillary to NHTSA's core interest in V2V safety and are at an even more nascent stage of development."

80 V2V Readiness Report, at p. 98. See also National Highway Traffic Safety Commission, Vehicle Safety Communications Project: Task 3 Final Report – Identify Intelligent Vehicle Safety Applications Enabled by DSRC, at 141 (March 2005).

81 See Comments of NCTA, at p. 13-14; See also HSTP-CITS-Reqs Global ITS Communication Requirements, ITU Technical Paper (Jul. 11, 2014), at p. 11-12 ("Safety applications do not require high bandwidth"), available at http://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-ITS-2014-REQS-PDF-E.pdf.

82 Federal Communications Commission, Amendment of the Commission's Rules Regarding DSRC Services in the 5.850-5.925 GHz Band, Report and Order, WT Docket No. 01-90 (rel. Feb. 10, 2004) at p. 16-17 ¶ 25. Under the band plan adopted by the Commission, there is one control channel and six service channels, two of which are designated for public safety applications. Channel 172 is dedicated to V2V signaling. Channel 184 is designated for higher-power public safety communications, but also for shared use by "non-public safety DSRC operations." Id.

83 V2V Readiness Report, at p. 56. In the report's section discussing three potential V2I applications – real-time traffic information, weather updates and Applications for the Environment (AERIS) – NHTSA cautions that other DSRC applications must not congest the BSM channel. "It is critical that safety messaging not be compromised due to broadcasting more data for V2I." Id. at p. 13.

84 A fact sheet describing the Department of Transportation's DSRC safety pilot in Ann Arbor, MI lists forward collision warning, lane change/blind spot warnings, emergency electronic brake light warning, and intersection movement assist as the DSRC safety applications being tested. All of these applications operate on a single safety channel using narrowband basic safety messages (BSMs). See U.S. Department of Transportation, Office of the Assistant Secretary for Research, "Intelligent Transportation Systems Safety Pilot: Model Deployment Technical Fact Sheet," available at http://www.its.DOT.gov/factsheets/technical_fs_model_deployment.htm.

85 From Section 8 on V2V applications of ITU Technical Paper: "Safety applications do not require high bandwidth. Infotainment, navigation, and vehicle monitoring applications require moderate to high bandwidth. Some require multiple channels (audio, video, etc.)." HSTP-CITS-Reqs Global ITS Communication Requirements, ITU Technical Paper (Jul. 11, 2014), at p. 12.

86 According to one study, "other drivers of near-future growth include the increased availability of high-speed wireless networks and cloud-based data services around the world, and the development of application programming interfaces (APIs) needed to create connected car software." Richard Vierecki et al., Connected Car Study 2015: Racing ahead with autonomous cars and digital innovation, Strategy& (Sep. 16, 2015), at p. 11, available at http://www.strategyand.pwc.com/global/home/what-we-think/reports-white-papers/article-display/connected-car-2015-study. Another found that "telecom operators are often said to be nervous about being restricted to the role of data pipe providers," but that "within the automotive industry, there is an opportunity to become much more if embedded telematics becomes the long-term de-facto connectivity method." GSMA and SBD, "2025 Every Car Connected: Forecasting the Growth and Opportunity" (Feb. 2012), at p. 2, available at http://www.gsma.com/connectedliving/wp-content/uploads/2012/03/gsma2025everycarconnected.pdf.

87 NHTSA, V2V Readiness Report, at p. 17 ("[DSRC]could address 81 percent of unimpaired light vehicle crashes").

88 V2V Readiness Report, at p. 26.

89 Id. at p. 27.

90 See ITS Petition to the FCC, supra note 67.

91 See "AT&T Reports Double-Digit Adjusted EPS and Free Cash Flow Growth, and 2.1 Million Wireless Net Adds in Second-Quarter Results," AT&T Newsroom (Jul. 23, 2015), available at http://about.att.com/story/att_second_quarter_earnings_2015.html.

92 See Aaron Smith, "US Smartphone Use in 2015," The Pew Research Center (Apr. 1, 2015), available at http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/.

93 Id.

94 For example, Waze allows any driver or passenger with a smartphone or connected tablet to passively crowd-source real-time traffic information to the Cloud. "After typing in their destination address, users just drive with the app open on their phone to passively contribute traffic and other road data, but they can also take a more active role by sharing road reports on accidents, police traps, or any other hazards along the way, helping to give other users in the area a 'heads-up' about what's to come." See "Waze: About Us," available at https://www.waze.com/about.

95 "However, some industry observers note that the federal Connected Vehicle program may already be out of date in that it doesn't include the most rapidly growing source of all traffic data – smartphones." See Patrick Marshall, "Can transportation agencies call on smartphones for traffic data?" available at http://gcn.com/Articles/2014/02/10/connected-vehicles.aspx?Page=1

96 Id.

97 Benkler Study, supra note 24, at p. 138.

98 In Section 8 of ITU Tech Paper on V2V applications: "safety applications do not require high bandwidth. Infotainment, navigation, and vehicle monitoring applications require moderate to high bandwidth. Some require multiple channels (audio, video, etc.)." HSTP-CITS-Reqs Global ITS communication requirements, at p. 12.

99 See U.S. Department of Transportation, "Transportation Sec. Foxx announces steps to accelerate road safety innovation" (May 13, 2015), available at http://www.nhtsa.gov/About+NHTSA/Press+Releases/2015/nhtsa-will-accelerate-v2v-efforts.

100 "It is NHTSA's view that, if V2V were not mandated by the government, it would fail to develop or would develop slowly. . . . [B] ecause the value of V2V to one driver depends upon other drivers' adoption of the technology, it seems unlikely to NHTSA that a manufacturer would volunteer to 'go first' with adding DSRC to its new vehicles, because those units would provide little benefit to their drivers until some critical mass of V2V equipped vehicles is achieved, ..." V2V Readiness Report, at p. 6.

101 Id. at p. 24.

102 V2V Readiness Report, supra note 50, at p. 230.

103 NHTSA, ANPRM, at ¶ 53.

104 See U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology "Costs Database: Unit Costs for DSRC-based Data Collection Equipment Costs Can Range From $4150 -$9200" (Jun. 27, 2014), available at http://www.itscosts.its.DOT.gov/ITS/benecost.nsf/SummID/SC2014-00330?OpenDocument&Query=Home. According to the V2V Readiness Report, the labor installation costs of a retrofit DSRC device would be $135. V2V Readiness Report, supra note 50, at p. 229-230.

105 For example, a refundable federal tax credit of $500 could conceivably equip 200 million used vehicles (roughly 75% of the fleet at the time the mandate becomes effective) by 2025 at a cost of $100 billion.

106 Id.at p. 28, citing NHTSA, "Description of Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications," Report No. DOT HS 811 731 (May 2013)

107 NHTSA, ANPRM, at ¶ 1. "By mandating V2V technology in all new vehicles, but not requiring specific safety applications, it is NHTSA's belief that such capability will in turn facilitate market-driven development and introduction of a variety of safety applications, as well as mobility and environment-related applications that can potentially save drivers both time and fuel." Id.

108 NHTSA, ANPRM, at ¶ 3.

109 U.S. Government Accountability Office, "Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist," Report to Congressional Requesters at 21-22 (September 2015).

110 See DOT AEB Press Release, supra note 47; See also Paul Stenquist, "On the Road to Autonomous Pause at Extrasensory," The New York Times (Oct. 25, 2013), available at http://www.nytimes.com/2013/10/27/automobiles/on-the-road-to-autonomous-a-pause-at-extrasensory.html?_r=3; Jurgen Dickmann et al., "How We Gave Sight To the Mercedes Robotic Car," IEEE Spectrum (Jul. 24, 2014), available at http://spectrum.ieee.org/transportation/self-driving/how-we-gave-sight-to-the-mercedes-robotic-car; Ellen Hall, "Can Cars Help Prevent Distracted Driving?" Esurance Blog (Sep. 26, 2014), available at http://blog.esurance.com/can-cars-help-prevent-distracted-driving/#.VZL4qUZkrm4.

111 The 76-77 GHz band was opened for unlicensed automotive radar in 1995. See FCC, "Amendment of Sections 15.35 and 15.253 of the Commission's Rules Regarding Operation of Radar Systems in the 76-77 GHz Band," 27 FCC Rcd. 7880, 7881 (Jul. 5, 2012); Benkler Study, supra note 24, at p. 139.

112 See "Ford Collaborates with Silicon Valley Innovation Ecosystem on Autonomous Vehicles, 3D Printing, Wearable Technology," Ford (Jun. 23, 2015), available at https://media.ford.com/content/fordmedia/fna/us/en/news/2015/06/23/ford-collaborates-with-silicon-valley-innovation-ecosystem.pdf ("Ford also announced today that Pre-Collision Assist with Pedestrian Detection technology, already available on Ford Mondeo in Europe, will be available in the United States next year on a Ford-brand vehicle. This continues Ford's plan to roll out the feature on most Ford products globally by 2019.")

113 NHTSA, Traffic Safety Facts 2013, supra note 49, at p. 70.

114 See National Transportation Safety Board, The Use of Forward Collision Avoidance Systems to Prevent and Mitigate Rear-End Crashes (2015), Special Investigation Report NTSB/SIR-15-01 ("NTSB Report"), at p. 17. http://www.ntsb.gov/safety/safety-studies/Pages/SIR1501.aspx

115 NHTSA, Traffic Safety Facts 2013, supra, at p. 70.

116 V2V Readiness Report, supra note 50, at p. 11.

117 NTSB Report, supra note 114, at p. 34-35.

118 Id. NTSB also warns that during the initial decade or more, drivers could resist or be misled by a V2V system that does not detect most other vehicles on the road. "A safety system that frequently fails to detect a conflict (even if such a limitation is by design) could easily become an unreliable system in the eyes of the driver, further necessitating the need for the comprehensive active safety system offered by a vehicle-based [sensing systems]."

119 See Ram Kandarpa et al., Final Report: Vehicle Infrastructure Integration Proof-of-Concept, Executive Summary – Infrastructure, U.S. Department of Transportation (Feb. 2009), at p. 16, available at http://www.its.DOT.gov/research_docs/pdf/29ExecutiveSummary.pdf.

120 Paul Alexander, David Haley, and Alex Grant, "Cooperative Intelligent Transportation Systems: 5.9-GHz Field Trials," Proceedings of the IEEE (2011), at pp. 1213-1235.

121 Both Google and Tesla have longstanding autonomous car research programs. See Molly Wood, "CES: Visions of Cars on Autopilot," NY Times Bits Blog (Jan. 6, 2015), available at http://bits.blogs.nytimes.com/2015/01/06/ces-visions-of-cars-on-autopilot/?_r=0. Toyota recently announced it plans to bring autonomous cars to market, possibly by 2017. See Alex Davies, "Toyota Finally Gets Serious About Self-driving Cars," Wired (Sep. 4, 2015), available at http://www.wired.com/2015/09/toyota-enters-self-driving-car-race/.

122 See Drew Harwell, "Tesla Cars Gain Self-Driving Sentience Overnight," Washington Post (Oct. 14, 2015), available at https://www.washingtonpost.com/news/the-switch/wp/2015/10/14/tesla-cars-gain-self-driving-sentience-overnight/.

123 See Joe Nocera, "Look Ma, No Hands!" The New York Times (Jun. 5, 2015), available at http://www.nytimes.com/2015/06/06/opinion/joe-nocera-look-ma-no-hands.html?_r=0. As of October 2015, Google's self-driving cars had logged 1,268,108 miles in "autonomous mode," where the software is driving the vehicle without assistance from the drivers. Google's cars have been involved in ten minor accidents since 2010. See "Google Self-Driving Car Project: Monthly Reports," available at http://www.google.com/selfdrivingcar/reports/.

124 See "GM Outlines Plans to Capitalize on the Future of Personal Mobility," GM Corporate Newsroom (Oct. 1, 2015), available at http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2015/oct/1001-gbc.html; see also Matt McFarland, "Can GM be a Disruptor in the Self-Driving Car Wars?" Washington Post (Oct. 2, 2015), available at http://www.washingtonpost.com/news/innovations/wp/2015/10/02/can-gm-be-a-disruptor-in-the-self-driving-car-wars/.

125 See John Markhoff, "Toyota Aims to Make Car a Co-Pilot for Drivers," The New York Times at B1 (Sep. 5, 2015), available at http://www.nytimes.com/2015/09/05/science/toyota-artificial-intelligence-car-stanford-mit.html.

126 Molly Wood, "CES: Visions of Cars on Autopilot," supra note 121.

127 Michele Bertoncello and Dominik Wee, "Ten ways autonomous driving could redefine the automotive world," McKinsey Insights (Jun. 2015), available at http://www.mckinsey.com/insights/automotive_and_assembly/ten_ways_autonomous_driving_could_redefine_the_automotive_world.

128 In its V2V Readiness Report, NHSTA estimates 37 years; the NTSB Report puts this timeline at 20-30 years. V2V Readiness Report, supra note 50. See also NTSB Report, supra note 114, at p. 35.

129 V2V Readiness Report at p. 117. See also Bishop, "Global V2X Deployment: Contrasts with U.S. Approach," Docket No. NHTSA-2014-0022 (Jan. 21, 2013), at p. 35.

130 See Electronic Communications Committee, "The harmonized use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS)," ECC Decision (08)01 (amended Jul. 3, 2015), available at http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC0801.PDF.

131 See Electronic Communications Committee, The European Table of Frequency Allocations and Applications In The Frequency Range 8.3 kHz to 3000 GHz (May 2015), at p. 121, available at http://www.erodocdb.dk/docs/doc98/official/pdf/ERCRep025.pdf.

132 Id. See also European Commission Digital Agenda for Europe, "Short Range, Mass Market" (May 9, 2014), available at http://ec.europa.eu/digital-agenda/en/short-range-mass-market.

133 See ECC Decision (08)01, supra note 130.

134 See Tiger Team Final Report, at p. 25.

135 See Explanatory Memorandum for ECC/DEC/(08)01, available at http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC0801.PDF.

136 V2V Readiness Report, supra note 50, at p. 116.

137 *Ibid.*

138 See Hideki Hada, "Intelligent Transportation Systems: Opportunities for Communication-Based Driving Support," Toyota Technical Center (2011), at p. 11, available at http://www.toyota.com/csrc/printable/9Hada.pdf. See also "Frequency Allocation Table of Japan," available at http://www.rf114.com/lib/download.php?code=tbl_board&seq_name=bseq&seq=765; Paul Spaanderman, "Spectrum Allocation for ITS: From Out of the EU Perspective," available at http://www.imobilitysupport.eu/library/imobility-forum/plenary-meetings/2015-1/5th-plenary-meeting-28-jan-2015-1/presentations/2737-18-paul-spaanderman-tno/file.

139 See John B. Kenney, "DSRC: Deployment and Beyond," Presentation at Toyota InfoTechnology Center (May 14, 2015), at p. 10, available at http://www.winlab.rutgers.edu/iab/2015-01/Slides/06.pdf.

140 V2V Readiness Report,, supra note 50, at p. 118.

141 *Id.* at 17; see also World Road Association (PIARC), International Federation of Automotive Engineering Societies (FISITA), "The Connected Vehicle" (2012), at p. 19, available at http://www.ssti.us/wp/wp-content/uploads/2012/08/connected-vehicles-report.pdf.

142 Notice of Ex Parte filed by James Barker on behalf of Toyota, ET Docket No. 13-49 (Dec. 19, 2014).

143 See Richard Bishop, Global V2X Deployment - Contrasts with US Approach, Bishop Consulting, at p. 3, available at http://www.noticeandcomment.com/Global-V2X-Deployment-Contrasts-with-U-S-Approach-fn-186558.aspx.

144 See "Toyota to Introduce V2X Communications on 2015 Japanese Models," Traffic Technology Today (Nov. 27, 2014), available at http://www.traffictechnologytoday.com/news.php?NewsID=64353.

145 PCAST Report, supra note 28, at p. 16.

146 Alton Burton Jr., "Winnik Forum: U.S. Federal Communications Commission's chief engineer explains that flexible use spectrum policy will readily accommodate the Internet of Things," Hogan Lovells Blog (Nov. 18, 2014), available at http://www.lexology.com/library/detail.aspx?g=0b64c821-c219-4d0d-8229-8b4a887dc7f7.

147 *Id.*

148 Covington & Burling, Prospects for U.S. Spectrum Management (June 2002) ("Covington & Burling Report"), at p. 4. "Narrow allocations are likely to be suboptimal: Any system that demands ex ante evaluation of competing technologies and their public benefits involves some risk of error, even by an expert agency." *Id.*

149 Michael Calabrese, "Principles for Spectrum Policy Reform," Working Paper, New America Foundation (Oct. 2001).

150 See Amendment to the Commission's Rules to Establish New Personal Communications Services, 8 FCC Rcd 7700 (1993).

151 See Policy Statement, Principles for Reallocation of Spectrum to Encourage the Development of Telecommunications Technologies for the New Millennium, 14 FCC Rcd 19868, 19870 (rel. Nov. 22, 1999) ("1999 Reallocation Order"), at ¶¶ 9, 11, available at https://transition.fcc.gov/Bureaus/Engineering_Technology/Orders/1999/fcc99354.txt.

152 Report of the Spectrum Policy Task Force, ET Docket No. 02-135 (Nov. 2002), available at http://sites.nationalacademies.org/cs/groups/bpasite/documents/webpage/bpa_048826.pdf ["Task Force Report].

153 *Id.* at 41.

154 *Id.* See also FCC, "Report of the Spectrum Efficiency Working Group," Spectrum Policy Task Force (2002), at p. 34-36, available at https://transition.fcc.gov/sptf/files/SEWGFinalReport_1.pdf.

155 *Id.*

156 *Id.* at p. 6.

157 *Id.* at p. 6.

158 Federal Communications Commission, "Chapter 5: Spectrum," National Broadband Plan: Connecting America, (2010), at p. 75, available at http://download.broadband.gov/plan/national-broadband-plan.pdf.

159 *Id.*

160 *Id.*

161 *Id.*

162 Gregory L. Rosston and Jeffrey S. Steinberg, "Using Market-Based Spectrum Policy to Promote the Public Interest," Fed. Comm. L.J: Vol. 50: Iss. 1, Article 4 (1997), available at **http://www.repository.law.indiana.edu/fclj/vol50/iss1/4**, at p. 94; see also Covington & Burling Report, supra note 148, at p. 1.

163 FCC, 1999 Reallocation Order, at p. 5. This vision of safe, autonomous vehicles was correct, except for the fact that the driverless cars being tested on the U.S. roads today neither need nor use DSRC communications, whether V2V or V2I.

164 *Id.* at p, 92; see also Covington & Burling Report, supra note 148, at p. 4: "As the pace of technological change increases, suboptimal allocations are likely to become obsolete even faster just as spectrum is urgently needed for new services."

165 See PCAST Report, supra note 28.

166 See Federal Communications Commission, Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Report and Order and Second Further Notice of Proposed Rulemaking, GN Docket No. 12-354, 30 FCC Rcd 3959 (rel. Apr. 21, 2015).

167 NTIA, "Promoting Spectrum Sharing in a Wireless Broadband World," NTIA Blog (Jan. 9, 2015), available at **http://www.ntia.doc.gov/blog/2015/promoting-spectrum-sharing-wireless-broadband-era**.

168 Aspen Institute, Dorothy Robyn (Rapporteur), Making Waves: Alternative Paths to Flexible Use Spectrum, Report of the Aspen Institute Roundtable on Spectrum Policy (2015), at p. 11.

169 *Id.* "As Intel's Peter Pitsch put it: 'If we've learned anything about spectrum policy over the last 30 years, it's that . . . old technologies and uses get locked in, and the . . . process slows innovation to the detriment of society.'"

170 Federal Communications Commission, 79 Fed. Reg. 69, 387 (proposed Nov. 21, 2014) (GN Docket Nos. 14–166 and 12–268; FCC 14–145) (to be codified at 47 C. F. R. pt. 74) ("Spectrum Access for Wireless Microphone Operations NPRM").

171 Benkler Study, supra note 24, at p. 75.

172 *Id.* at p. 74-75, 108-112.

173 *Id.* at p. 113-116.

174 *Id.* at p. 114-115. See also Jonathan Collins & Sam Lucero, "Wireless Technologies in Professional Healthcare," ABI Research (2011), at p. 24.

175 FCC, In the Matter of Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services, ET Docket No. 98-95, RM-9096, FCC 98-119 (rel. Jun. 11, 1998) ("1998 NPRM"), at p. 8.

176 See 1999 Reallocation Order at p. 5-6, citing ITS America study.

177 See 1998 NPRM, at p.7 note 28.

178 See 1999 Reallocation Order, at p. 5.

179 5 GHz FNPRM, at ¶ 75.

180 *Id.* at ¶ 101.

181 "Despite 18 months of meetings and presentations, there was no clear consensus or compromise for a single proposal," Tiger Team Final Report, at p. 8.

182 See Alan Chachich et al., DSRC-Unlicensed Device Test Plan, U. S. Department of Transportation (August 2015), available at **http://www.its.dot.gov/connected_vehicle/pdf/DSRC_TestPlanv3.5.3.pdf**.

183 *Id.*

184 *Id.* at p. 6.

185 *Id.*

186 Notice of Ex Parte filed by Frederick M. Joyce on behalf of the Alliance of Automobile Manufacturers, the Association of Global Automakers, and Cisco, ET Docket No. 13-49 (May 6, 2015).

187 See Comments of Time Warner Cable Inc., ET Docket No. 13-49 (May 28, 2013), at p. 13.

188 *Id.*

189 *Id.* at p. 7.

190 *Id.*

191 See Comments of Qualcomm, supra note 44; Tiger Team Final Report, at p. 7-8.

192 See Tiger Team Final Report, at p. 7-8.

193 See Comments of Qualcomm, supra note 44, at p. 6.

194 *Id.* at p. 7.

195 *Id.* at p. 12. Qualcomm explains that although 802.11n and 802.11ac are capable of using channels wider than 20 MHz (80 and even 160 MHz OFDM channels in the case of 802.11ac), "all of these new channels have the same subcarrier spacing (312.5 kHz) as that of the basic 20 MHz channel first defined in the IEEE 802.11a standard." *Id.* at p. 12, note 10.

196 *Id.*

197 See Tiger Team Final Report, Appendix D: USDOT Participation in IEEE Tiger Team re: 5 GHz Spectrum Sharing, at p. 27.

198 See Tiger Team Final Report, at p. 17.

199 See Letter from 5.9 GHz Industries to the U. S. Department of Transportation, the U.S. Department of Commerce, and the Federal Communications Commission, News Anchor, NBC 10 Philadelphia, to Robert Toll, President (Sep. 9, 2015), available at **https://www.commerce.senate.gov/public/_cache/files/1a215719-31b5-41e2-ad5b-e577931cceee/107C048C17A898C0316921465F4A0A0C.final-industry-stakeholder-letter-on-5.9.pdf**.

200 *Id.* See also FCC, "Report of the Spectrum Efficiency Working Group," Spectrum Policy Task Force, at 34-36 (2002), available at **https://transition.fcc.gov/sptf/files/SEWGFinalReport_1.pdf**.